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A LINEAR PROGRAMMING MODEL TO DETERMINE THE LEAST-COST TRANSPOR--ETC(U)
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A LINEAR PROGRAMMING MODEL TO DETERMINE THE LEAST-COST TRANSPORTATION ASSET MIX TO DEPLOY A FIELD ARTILLERY BATTERY

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Final Report,
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A thesis submitted to Auburn University, Auburn, Alabama, in partial fulfillment of the requirements for the degree of Master of Science.

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An integer programming model is developed to determine the mix of transporting vehicles required to deploy a field artillery battery and minimize the cost associated with the movement. Constraints include the equipment transported, carriers available, deployment time, maximum train length, and rail motive power. The decision variables are the feasible load plans based on equipment and cargo compartment dimensions and carrier payload restrictions. Motor transportation appears to be the optimal mode to minimize transportation costs when time permits.

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A LINEAR PROGRAMMING MODEL TO DETERMINE THE LEAST-COST TRANSPORTATION ASSET MIX TO DEPLOY A FIELD ARTILLERY BATTERY

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A LINEAR PROGRAMMING MODEL TO DETERMINE THE LEAST-COST TRANSPORTATION ASSET MIX TO DEPLOY A FIELD ARTILLERY BATTERY

John Moody House

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

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Degree of

Master of Science

Auburn, Alabama

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John Moody House

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Signature of Author

1 November 1979
Date

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VITA

John Moody House, son of John Wiley and Mary Charles (Kirkland) House, was born October 12, 1953, in Columbus, Georgia. He attended Muscogee County Public Schools and graduated as Valedictorian from Columbus High School in 1971. In June, 1971, he entered Auburn University and received the degree of Bachelor of Science (Business) in June, 1975. Upon graduation and commissioning in the Field Artillery branch of the United States Army, he served three years with the 82D Airborne Division at Fort Bragg, North Carolina, then returned to Auburn University and entered Graduate School in September, 1978. He married Marilyn, daughter of William Demar and Virginia (Wyche) McEathern in September, 1973. They have two daughters, Shannon Virginia and Amanda Beth.

THESIS ABSTRACT

A LINEAR PROGRAMMING MODEL TO DETERMINE THE
LEAST-COST TRANSPORTATION ASSET MIX TO
DEPLOY A FIELD ARTILLERY BATTERY

John Moody House

Master of Science, December 13, 1979
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A linear programming model was developed to determine the mix of transporting vehicles required to deploy a field artillery battery that would minimize the cost associated with the movement. Constraints for the model included the equipment to be transported, the carriers available, and the time available. Additional constraints as to maximum train length and motive power were applied to the rail mode. All answers were restricted to integer values.

The model functioning was demonstrated for two routes (Fort Benning, GA, to Charleston, SC, and Fort Benning, GA, to San Francisco, CA) and three time scenarios (three, seven, and thirty days). Certain data required was not readily available which required estimates of their values. The results indicated that motor transportation using the unit's organic vehicles was the preferred mode for the majority of the equipment as long as time or another factor did not preclude its

use. The most important result was that the study indicated that linear programming is a valuable tool in transportation planning.

ACKNOWLEDGEMENTS

Without the assistance of a great number of people, this thesis could not have been written. Certainly I must thank the librarians of the Ralph Brown Draughon Library at Auburn University, the Air University Library at Maxwell Air Force Base, AL, and the Infantry School Library at Fort Benning, GA. Their efforts provided numerous sources. A special thanks must go to Linda Anderson of the Transportation School Library at Fort Eustis, VA, for her assistance in obtaining copies of many studies related to this thesis.

Dr. Neil Martin and Dr. William Hardy of the Agricultural Economics Department made possible my use of the IBM integer programming software package available at the Auburn University computer center. They were both willing to listen to and answer the many questions I had. Their guidance enabled me to utilize the software package with little difficulty.

Many individuals associated with the military gladly gave their time and energy to assist me. Their contributions are indicated by the information referenced to them throughout the thesis. I will always be especially indebted to MAJ Danny E. Harris and Dorothy Roland of the Fort Benning Installation Transportation Office and SGT Phillip Files of the 197th Infantry Brigade for their efforts in providing the information I requested.

The employees of the Southern Railway Company displayed an incredible degree of enthusiasm in providing technical and cost data for my study. My gratitude must include Gordon Bingham and Robert Redmond of Columbus, GA; Ed Martin of Washington, D.C.; and Gary Wolf of Atlanta, GA. One Southern employee that must not be forgotten is my father, John W. House. He opened many doors and allowed me to capitalize on his many years of railroad experience.

I owe a special debt of thanks to my wife, Marilyn. Her many hours of typing and proofreading must be recognized for without her encouragement and assistance, the completion of this study would have been much more difficult, if not impossible.

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LIST OF ABBREVIATIONS

AACG: arrival airfield control group

ACL: allowable cargo load

AFM: Air Force manual

AFR: Air Force regulation

ALCE: airlift control element

ATMCT: air terminal movement control team

AR: Army regulation

CONEX: Container Express

CONUS: Continental United States

COSCOM: corps support command

CRAF: Civilian Reserve Air Fleet

DACG: departure airfield control group

DFRIF: Defense Freight Railway Interchange Fleet

DOD: Department of Defense

FM: field manual

ITO: Installation Transportation Office

MAC: Military Airlift Command

MCA: movement control agency

MCC: movement control center

MSC: Military Sealift Command

MTMC: Military Traffic Management Command

NAVSO P: Navy Supply Office publication

TASCOM: theater army support command

TM: technical manual

TMO: transportation movement office

TRS: transportation railway service

USAIC: U.S. Army Infantry Center

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I. INTRODUCTION

Importance

The transportation of personnel and equipment is crucial to any military operation. Unit failure to reach its destination or objective results in mission failure. History has demonstrated that logistical problems can decide the fate of armies. Napoleon's disastrous retreat from Moscow in 1812 was due in part to the failure of his logistical system to adequately supply and transport his troops and equipment. The loss of the German Sixth Army at Stalingrad in 1943 was the result of the failure of the German Air Force to adequately resupply the ground combat units. The importance of an efficient logistics system cannot be overstated. An efficient transportation system is one element of this requirement.

Today, costs severely restrict unit deployments. While perhaps not relevant in a wartime situation, it certainly is important in peacetime. Funding is often very difficult to obtain thus severely restricting the resources available for movements. Other constraints must also be considered. The time allowed for deployment would replace cost in importance during a war. The transportation assets available and the characteristics of the unit to be moved are additional constraints. Some method must be used to combine all these factors and produce a transportation plan for the movement of a unit. Linear programming is one possible method.

A linear programming model can be constructed to minimize the linear cost function associated with the use of various transportation assets subject to several constraints. This would allow a unit with the assistance of a computer to quickly determine the most cost effective transportation modes to use under various conditions. If the personnel and equipment transported by each carrier is an output of the model, additional time would be saved in the planning process. Time is always important.

Military Transportation

The movement of military units is a very complex planning process due to the numerous agencies and levels of command involved. Each level of command from company, battery, or troop to battalion or squadron and higher has an individual (or a group of personnel) who are responsible for the unit's movement planning. Additionally the military post where the unit is located has an Installation Transportation Officer whose function is to coordinate transportation operations. His staff handles a variety of tasks from supervising the shipment of household goods to coordinating the movement of a unit to a location beyond the physical limits of the installation.

The transportation of an Army unit beyond the boundaries of the post where it is assigned may involve coordination with several agencies. For example, the Military Traffic Management Command, Eastern Area (MTMC) in Bayonne, New Jersey, coordinates the movement of units from Fort Benning, Georgia, moving by surface means (Roland and Porter, 1979). Military air movements must be coordinated with the Military Airlift Command (MAC) which has its headquarters at Scott Air Force

Base, Illinois. The Military Sealift Command (MSC) headquartered in Norfolk, Virginia, controls all water movements (Hansen, 1979b). These agencies compute the rates charged for the transportation modes under their jurisdiction and allocate the various transportation assets.

Military movements may involve both the use of civilian and military transportation assets. This study will utilize military assets wherever possible.

For example, the Defense Freight Railway Interchange Fleet (DFRIF) is composed of railcars owned by the Department of Defense (DOD) to support peacetime and wartime requirements that cannot be met by the commercial resources available (Del Mar, 1977). These cars are shipped to any installation in the continental United States (CONUS) which requires them. If a unit needs railcars from the DFRIF, the Installation Transportation Office (ITO) contacts MTMC and requests them. Civilian locomotives, however, pull the trains composed of these railcars (Roland and Porter, 1979). This is an example of civilian and military assets working in combination.

Civilian motor carriers can be contracted to transport Army equipment or Army trucks can be used. While military aircraft are preferred to transport personnel and equipment by air, commercial aircraft frequently transport personnel. A Civilian Reserve Air Fleet (CRAF) exists for emergency augmentation of the military's air assets. The Military Sealift Command operates civilian manned ships in support of all DOD components (Moore, 1978). Ships manned by naval personnel also may be utilized.

In a theater army, a transportation movement control agency (MCA) is established to provide centralized control of the transporta-

tion assets available (see Figure 1). The nerve center of the MCA which coordinates the transportation activities in the theater army is the movement control center (MCC). This element performs the movement management functions required. The area where the transportation system operates is divided into regions to ease the control efforts. Each geographic region has a transportation movement office (TMO) which coordinates the transportation requirements for the region (FM 55-10, 1977).

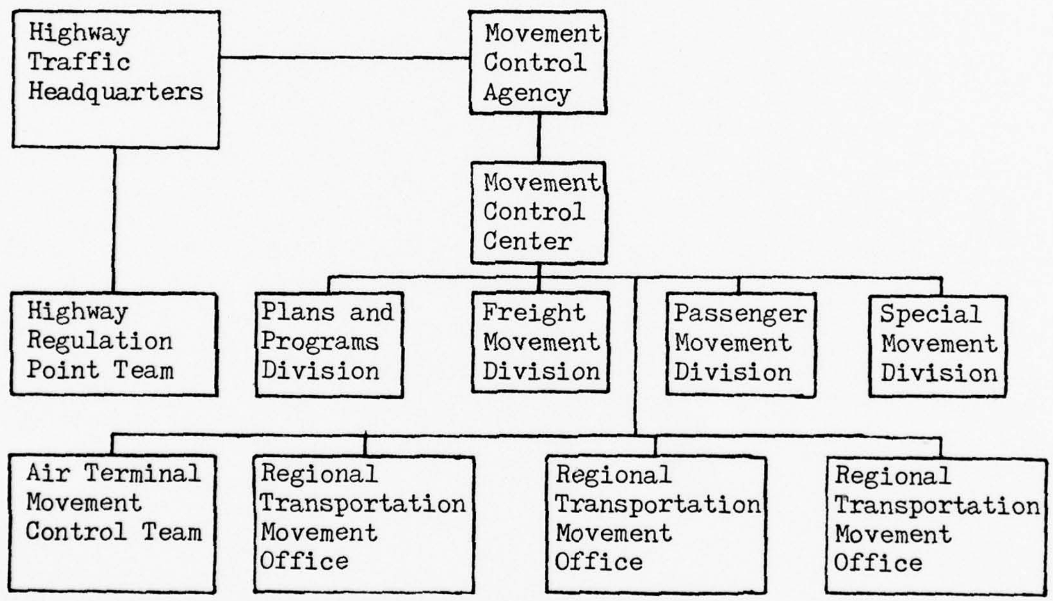

Figure 1

Theater Army Transportation Movement Control Agency

Air terminal movement control teams (ATMCT) are attached to the MCC to operate Air Force terminals in the theater of operations. The number assigned and their locations depend on the number and location

of major air terminals in the theater. Highway traffic is regulated by a highway traffic headquarters established subordinate to the MCA. Actual traffic control is performed by military police units. Normally the highway traffic headquarters is located with the MCC (FM 55-10, 1977).

Transportation movement management at corps level is performed by the corps support command (COSCOM) movement control center (see Figure 2). The corps MCC's functions are generally the same as for the theater level MCC but are limited by the level of command and geographic region where assigned. The transportation assets available also limit the corps MCC. A highway traffic headquarters is established subordinate to the MCC to regulate motor movement. Transportation movement offices, highway regulation point teams, and air terminal movement control teams are attached to the corps MCC as required at critical locations to coordinate and monitor the movement program (FM 55-10, 1977).

Each of the agencies mentioned could use a mathematical model in their planning sequence. Lower levels of command could also, provided they had access to a computer system.

While this study will focus on the movement of a field artillery battery, any unit that size or larger could utilize the model. Computer techniques allow the solution of such large scale mathematical problems to be identified quickly. This would be extremely valuable to a battery or battalion since movement planning is an additional duty given to an individual and is usually developed manually. Any time saved in accomplishing a secondary duty would increase the individual's ability to properly carry out his primary duty.

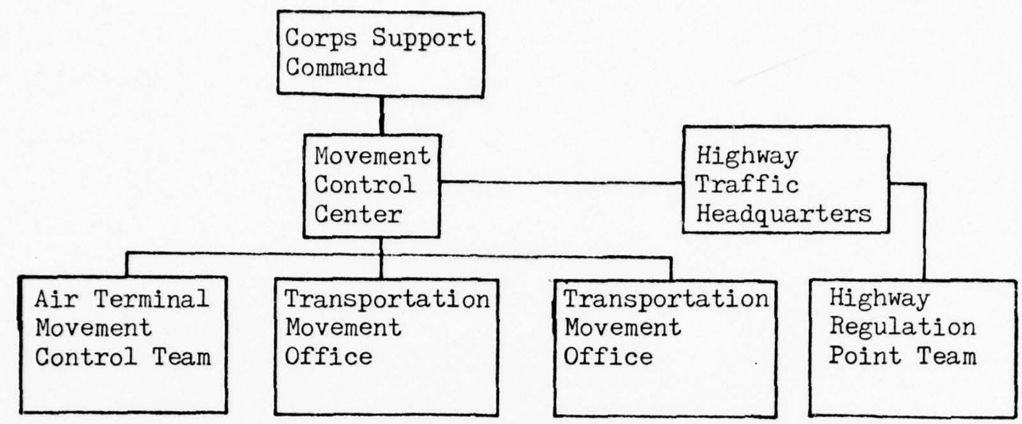

Figure 2

Corps Transportation Movement Control Center

Mode Selection

The model formulated is a method of facilitating movement management which is defined as "planning, coordinating, programming, and monitoring the allocation and use of available transportation resources in accomplishing the commander's movement requirements" (*FM 55-10*, 1977, p. 1-5). The transportation assets are allocated based on a priority system (*FM 55-10*, 1977). The minimization of the costs associated with the movement will be used to indicate the priorities of the types of transport vehicles (rail, truck, and air) utilized.

The movement capability of the transport modes affects the use of certain assets. The capability of a shipping or receiving agency is its ability to receive, load, unload and release transportation vehicles during a specified period of time. The labor available, quantity of shipments, type of shipments, and the materials handling equipment

available will affect this capability. The capability of a transport mode organization is based on the organization's lift capability and the average turnaround time. This lift capability is affected by operator availability, equipment status, and length of haul (FM 55-10, 1977).

There are several basic guidelines to be used in determining the transport mode to be selected. The first guideline is to provide the service needed based on established priorities and the characteristics of the shipment as they affect security, political, and transportation service factors. The second is to use the most economical mode. The third is to minimize cargo rehandling. This can be facilitated by mode combinations such as trailer on flatcar (piggyback) operations. Containerization is another method of consolidating cargo and minimizing handling requirements. The final guideline is to allocate the available transportation assets to fulfill known requirements. A reserve of transport vehicles should not be maintained to handle unknown requirements. Unforseen transportation requirements should be processed in accordance with the existing priority system (FM 55-10, 1977). The order of economy, most effective use, capabilities, and limitations of air, motor, rail, and water transportation modes which govern mode selection are given below.

Water transportation, the most economical of the four modes, is the primary trans-ocean transportation means and the supplementary mode for inland surface movement of large quantities of material. Ships can operate in virtually any weather and carry any commodity. Water transportation can be useful in relieving other modes for more suitable use. Limitations include slow speed, lack of flexibility due to terminal and

waterway restrictions, vulnerability to attack, and difficulty of replacement (FM 55-10, 1977). The severe restrictions placed on inland waterway use due to the lack of navigable rivers precludes its consideration in this study as only movement within CONUS will be modeled.

Rail transportation is considered the main inland means used for maintaining a continuous flow of a large volume of cargo over long distances. Rail capabilities include all weather operation and the largest sustained ton-mile capacity of the modes considered. Any commodity can be transported due to the specialized equipment and services available. Rail limitations include: the lack of flexibility due to fixed routes, the transportation of certain items prevented due to route clearances, the requirement for motive power in addition to railcars, high vulnerability to interdiction by an enemy force (FM 55-10, 1977).

Motor transport allows an integrated transportation system to be developed by linking with other modes. Trucks are the primary means for conducting distribution operations and logistical support in a combat zone. Motor transports have tremendous flexibility over trafficable terrain. A variety of special purpose equipment allows almost any commodity to be moved by this mode. Weather, terrain, and enemy action can severely restrict the use of motor transports. The major limitation is the large number of men and pieces of equipment necessary for sustained line haul operations over long distances (FM 55-10, 1977).

Air transportation, the most expensive mode, is most effective as a means of expediting the movement of essential cargo and supplementing the use of surface modes when they face terrain restrictions.

This mode has the greatest speed potential and flexibility with respect to terrain obstacles. When these factors are combined with a large lift capability and long distances, air may be more economical than the other modes. Air transport limitations include restrictions resulting from climate and landing/take-off areas and a high ton per mile operating cost (FM 55-10, 1977).

Objective

The objective of this thesis is to formulate an integer linear programming model that will calculate the transportation assets required to deploy a field artillery battery within CONUS and minimize the cost associated with the movement. The mix of transporting vehicles required and their loads will be subject to several constraints: transportation assets available, personnel and equipment to be moved, deployment time allowed, rail motive power, maximum train length in railcars, and the feasible load plans which are determined based on equipment and cargo compartment dimensions and carrier payload restrictions.

Limitations

A basic limitation of this type of study is that only linear functions can be used in the model. A non-linear function requiring consideration must be approximated by a linear function. This may result in a model that is not a representation of the real world. The objective associated with such an approximation is to insure that the difference between the model and reality is slight.

A review of the literature available revealed that most of the important work in this area has been classified by the government. This

has prevented a complete literature review being accomplished in order to insure that there is not accidental inclusion of classified data in the thesis.

The constraints to be formulated can be further separated into many specific factors. Some of these may not be available, thus requiring estimates of their actual value. The results of the model may not reflect reality, however, the assumed data will provide a means of demonstrating the functioning of the model under the conditions specified. Such assumptions could affect the model's use by a unit commander. Much of the data (such as weather factors) will require updating before the model can be used. The pressures of time might prevent the thorough research of the factors applicable to the situation at hand.

Organization

The remainder of the paper will be divided into four additional chapters. The Review of Literature will present the results of other studies in this subject area. The Methodology will explain the linear programming techniques used in formulating the model. Any special consideration or assumptions required for this situation will be included. An evaluation of the solution to the model follows in the Results. The final chapter, Conclusions, will include decisions resulting from the use of the model and recommendations for modifications of its present form.

II. REVIEW OF LITERATURE

The literature in the fields of transportation and linear programming was reviewed to develop the model presented. Linear programming techniques have been applied to numerous military and non-military transportation problems. Several of these applications will be briefly discussed. Other applicable sources include those providing various approaches and factors used in solving transportation problems. The military services utilize several such publications in movement planning. The remainder of this chapter will be divided into two major sections: Linear Programming with Non-Military Applications and Military Applications subheadings and Reference Data with Field Manuals, Technical Manuals, Regulations, and Other Sources subheadings.

Linear Programming

Non-Military Applications

Many linear programming algorithms have been developed to solve transportation problems without being specifically designed for a given application. The classical transportation (or distribution) problem involves the minimization of a cost function subject to supply and demand constraints (Wagner, 1975). This problem has many applications and is relatively easy to solve. The addition of other types of constraints can severely increase the computational effort required to obtain an optimal solution.

Problems with upper and lower bounded variables have been solved by models developed by Wagner (1973) and Dunlay and Gualda (1979). The model formulated by Dunlay and Gualda using the Out of Kilter algorithm was applied to truck and barge limestone transportation in Brazil. Glover, Klingman, and Ross (1974) developed an algorithm for formulating a transportation problem with an additional constraint as a classical transportation problem. The procedure requires transforming the additional linear constraint into an equivalent bounded partial sum of variables which involves one node constraint. The primal simplex method has been used to solve constrained transportation and transshipment problems by exploiting the triangular structure of the problems (Klingman and Russell, 1975; Glover, Karney, Klingman, and Russell, 1978).

Integer programming methods have also been used to resolve transportation problems by treating vehicle routing as a traveling salesman problem (Magnanti and Simpson, 1978). Branch and bound techniques have been developed to solve fixed charge transportation problems (Kennington and Unger, 1976) and knapsack problems (Kolesar, 1967; Greenberg and Hegerich, 1970).

Large linear programming models are often difficult to solve due to the computational time required. One method of alleviating this problem is to break the original problem into blocks after a near optimal solution has been obtained by solving the problem under conditions almost identical to those required. This was performed by Atabegov and Linis (1971) in their discussion of the automatic control system for civil aviation in the USSR. The size of the model formulated for this thesis is well within the capacity of the computer facilities present.

There are times when cost may not be the most important consideration in a transportation problem. Lee and Moore (1973) developed a goal programming model for a problem involving several conflicting objectives: schedule contracts, union contracts, stable employment, and minimum transportation hazards. Yu and Hawthorne (1976) formulated a goal programming model for use by urban planners in developing an appropriate intracity transit system. Goal programming could be applied to a military transportation problem by using the minimization of cost and deployment time as goals that would vary in importance with each situation. That approach was not taken here since a maximum deployment time was assumed a constraint.

Underwood and Leake (1977; 1978) formulated a linear and a nonlinear model to study the costs associated with intercity transportation in Great Britain. There was no significant difference between the two solutions. Aronson (1975) developed a heuristic transportation scheduling algorithm and compared it to a linear programming model of the same problem. The simplicity of the heuristic approach was an advantage over the linear programming model but an optimal solution was not generated.

Dynamic transportation problems have been solved by such techniques as presented by Tapiero and Soliman (1972) and Merchant and Nemhauser (1978). Tapiero and Soliman formulated a discrete time model as a nonlinear, nonconvex mathematical program and used a piecewise linear model to compute the answer. Merchant and Nemhauser presented a system of differential equations to solve three types of problems: minimization of transport time using linear programming; minimization of inven-

tory and transportation cost using parametric programming; and minimizing a quadratic cost, unconstrained transportation problem analytically. Mitsumori (1978) developed a dynamic flow model where the number of vehicles required to satisfy the transportation demand as it varies with time is calculated. The number of transporting vehicles and their operating costs are two basic elements of the model developed in Chapter 3.

A linear programming model for cargo movement structured to handle "special" and "regular" cargo types with restrictions as to the carriers allowed to transport each was formulated by Gould (1971). Transshipment between carriers was allowed and additional capacity outside the carrier fleet could be purchased. The model was designed to minimize the cost associated with moving the cargo over certain routes subject to several constraints. In an earlier study, Gould (1969) developed a model to determine the optimal size of a road transport fleet. Optimization was accomplished by minimizing the total cost of the fleet which was a function of fixed and variable costs for company owned vehicles and the hiring cost necessary to obtain vehicles outside the fleet to haul excess cargo, less the savings from delicensing trucks during slack periods.

A scheduling and routing model for air transportation was presented by Levin (1971) where the variables assumed values of zero or one. A branch and bound algorithm was used to derive the answer. A recursive algorithm is used by Air Canada in scheduling flight itineraries (Bourque, Ferland, and Rousseau, 1977). The model first generates a set of feasible itineraries then an optimizing algorithm, using this feasible set, generates the optimal combination.

A transportation model for calculating the optimal operating levels for a regional multi-modal passenger transportation network was developed by Nihan and Morlok (1976) where the objective function minimized total annual transportation costs. Constraints included speed limits, capacity restrictions, demand requirements, minimum profit level, and accessibility to the various modes. The model was a component of the Composite Network Generation and Evaluation Model originally formulated for the federally funded Northeast Corridor Project.

Military Applications

Linear programming techniques have been used by the military in many areas. Dantzig and Fulkerson (1954) developed a model using the simplex algorithm to determine the minimum number of tankers required to meet the US Navy's fixed schedule of fuel oil requirements. A more recent application of linear programming to a naval problem is the Marine Amphibious Deployment Simulator (MARADS). A system of four computer programs is used to simulate amphibious deployment operations including loading and deploying the combat force to the objective area, landing the assault force, and supporting the landing force once ashore. The embarkation and movement program uses an integer programming algorithm to compute the transport fleet required to carry the assault force, the assignment of cargo to specific compartments, and the time required for the operation. A weighting factor is used to differentiate the shipping available (D'Esopo and Lefkowitz, 1965).

In 1965, the Mobility Forces Division of the Office of the Assistant Secretary of Defense for System Analysis was tasked with the

development of a formal approach to the military transportation system using computer models. This was viewed as beneficial since the military transportation system has a specified framework and experiments with actual vehicles are expensive. The complexity of such a massive undertaking resulted in the formulation of several related models instead of one large model. A linear programming model named POSTURE was developed as the focal point of the interrelated models (Nolan and Sovereign, 1972).

Two simulation models were developed to provide input to POSTURE. SOAR (Simulation of Airlift Resources) provided airlift data and SITAP (Simulation for Transportation Analysis and Planning) provided sealift data. POSTURE then determined the least cost resource set required to meet US strategic planning. Costs were defined for a ten year peacetime system. POSTURE was used to compute the force size but not to select equipment types (Nolan and Sovereign, 1972).

SOAR was designed to simulate the deployment of air resources for a maximum of ninety days. Aircraft productivity in ton-miles per day, aircraft utilization rates, airbase capacities, marginal productivity of airbase resources such as materials handling equipment, and marginal productivity of aircraft resources such as air crews were computed. SITAP has been used to determine the effects of ship queueing for port resources, convoying, and multiple port use (Nolan and Sovereign, 1972).

Nolan and Sovereign (1972) point out that recursive analysis techniques like combining linear programming and simulation are very beneficial. Linear programming can be used to provide guidance concern-

ing allocation of resources while simulation models can furnish operational information on productivity and can evaluate the derived schedules in varied environments.

Many other models for strategic deployment have been formulated. The Research Analysis Corporation developed a model which used cargo weight to denote capacity and derived a mixed mode transportation system because such a system would be less vulnerable to enemy action than a single mode system. Operation and maintenance costs, initial investment costs, and research and development costs were included (Fitzpatrick and Whiton, 1966; Wenthing, Fitzpatrick, O'Brien and Whiton, 1966). Weeks (1969) has described a Research Analysis Corporation model which includes attrition rates in a strategic deployment linear programming model. A linear programming application to the deployment of an assault support helicopter battalion was presented in an Armed Forces Staff College student paper (Grier, 1973).

A binary linear program has been applied to the United States Air Force LOGAIR feeder routes. LOGAIR is the contract air cargo system to provide freight transportation logistical support to CONUS military installations from the five Air Logistics Centers. A branch and bound algorithm was used to minimize a total cost function (Boudreaux and Olansen, 1977).

Reference Data

There are many documents produced by military organizations concerning transportation which were consulted for data on military movements. Other sources were used as examples of the types of information important to such a study. The following sections will

describe the types of data found in these sources. The actual information used will be referenced in Chapter 3.

Field Manuals

The responsibilities and functioning of transportation agencies were outlined in Chapter 1. A more detailed explanation of those organizations is given in FM 55-10 (1977). Factors that restrict transportation operations and the planning procedures to minimize these problem areas are described. For example, constraints affecting all movements include accidents, equipment failures, political considerations and security requirements. Cargo should be transferred between carriers as little as possible and containerized and palletized as much as possible to expedite movement. Sanitation facilities for personnel must be provided. The cubic size and the weight of the cargo must also be considered. The facilities of the shipping, intermediate, and receiving installations must be determined while remembering the ability of any installation to perform the assigned mission is limited by the weakest element. Storage space and materials handling equipment must be allocated. The track capacity of rail yards; number, direction, and capacity of runways; loading and unloading ramps; servicing road net; passenger, billeting, feeding, and processing capacity; and terminal operating personnel must be considered. Additionally, highway and rail movements are restricted by bridge and tunnel capacity (FM 55-10, 1977).

A crucial factor in military operations is the likelihood of enemy action at critical points and movement locations. Critical points are structures or features that limit overhead clearance, width, or

prevent the passing of two directional traffic on a highway. Examples are bridges, ferries, overpasses, underpasses, construction sites, road junctions, and railroad crossings. Critical movement areas require close supervision by movement control personnel to prevent the restriction of traffic flow. Examples are terminals, international borders, and intermode transfer points (FM 55-10, 1977).

A more detailed explanation of rail transportation is given in FM 55-20 (1974). A Transportation Railway Service (TRS) is established in the theater army support command to handle rail operations and is responsible for maintaining the rail assets available to the command. Facilities must be maintained or constructed to allow the loading and unloading of personnel and equipment. Fuel and water supply points must be established. Railcars must be utilized to insure maximum loading. Special clearances for oversize loads may be required for certain routes. The different track gages encountered between countries must be considered in planning the cars needed for movements that cross international borders. Tracks should not be built near stream banks or marshland to avoid erosion of the track bed and tracks running through cuts subject to rockslides should be avoided. Steep grades and sharp curves severely increase the motive power required. Double or multiple tracks which allow two directional traffic are preferred but are not mandatory as long as adequate sidings are provided. Enemy activity may require armored trains, sandbags on cars, and track reconnaissance aircraft.

The technical aspects of rail movement are discussed and formulas furnished for calculating the system capacity, railcars re-

quired, motive power required, operating personnel necessary, bridge capacity, and supplies required for rail operations. Characteristics of railcars and locomotives are also provided (FM 55-20, 1974).

FM 55-30 (1974) discusses the aspects of Army motor operations. Highway charactersitics such as width, surface material, grades, overhead clearances, and water crossings affect motor transportation. Guides, escorts and security personnel must be provided. Civilian controls in areas along the route must be ascertained. Motor transportation combines well with other modes in certain operations such as trailer on flatcar and container on flatcar rail movements and roll-on/roll-off and lift-on/lift-off ship movements. Formulas and planning factors are given for the calculation of the capabilities of the motor system available or desired.

Terminal operations are discussed in FM 55-60 (1970). The functions of air, motor, rail, and water terminals and the units available to operate them are listed. Planning data is furnished to determine terminal capacity.

Containerization is discussed in FM 55-70 (1975). The benefits of containerization include reduced handling resulting in less manpower, breakage, and pilferage and reduced packaging requirements resulting in less manpower, freight cost, and preparation time.

The data and procedures required for moving units by air are provided in FM 55-12/AFM 76-6 (1974). Allowable cargo loads (ACL), or payloads, of various aircraft and other characteristics such as seating capacity are discussed. Data is supplied to facilitate determining the aircraft required for an operation.

FM 55-13/AFM 76-12 (1974) presents example load plans for various equipment types in C5 aircraft. The examples given were used to determine the types of load plans possible for a field artillery battery.

FM 55-19 (TEST) (1976) addresses the control elements required for air operations such as the Airlift Control Element (ALCE) composed of Air Force personnel who control and coordinate Air Force airlift operations, the Departure Airfield Control Group (DACG) which is the liason between ALCE and the deploying unit, and the Arrival Airfield Control Group (AACG) which assists the deploying unit at the destination and returns all tiedown devices and pallets to ALCE.

The technical aspects of transportation units and equipment are consolidated in FM 55-15 (1968). The formulas and planning factors in many of the previous manuals are given by this reference. Many general planning factors used are also consolidated in FM 101-10-1 (1971).

Technical Manuals

Technical manuals applicable to highway transportation include TM 5-312 (1968), TM 55-310 (1969), and TM 55-312 (1971). TM 5-312 provides data for determining bridge capacity and classification. Highway bridges are classified as to capacity by a numbering system also used to classify military vehicles. Rail bridge classification which uses a different numbering system is also discussed. Examples of the information given by TM 55-310 include the requirements for a fifteen minute rest halt at the end of the first hour and a ten minute halt every two hours thereafter. TM 55-312 states that a maximum of sixteen men may be loaded in a $2\frac{1}{2}$ Ton truck for trips over four hours long and twenty for moves less than four hours.

Procedures for deploying personnel and equipment by air are discussed in TM 55-450-15 (1971). The responsibilities of the transporting and transported commander are listed in addition to planning data for air movements. Floor diagrams of most Air Force and Army aircraft and the applicable technical considerations such as ACL, seating capacity, floor strength, and cruising speed are provided. Elements that must be considered also include the size and shape of the cargo compartment, center of gravity limits, and loading aids available. Two additional technical manuals were used to determine feasible aircraft load plans: TM 55-450-10/1/AFM 76-3 (1967) and TM 55-450-10/2/AFM 76-4 (1971).

Regulations

Several regulations were found useful in this study. AR 55-29 (1971) establishes the procedures for moving military owned and operated vehicles, commercial movements of oversize or overweight military cargo, and other special commercial and military movements over public highways in CONUS. Data provided includes the requirement for drivers to rest eight hours for every ten hours of driving during a twenty-four hour period, rest periods for drivers begin twelve hours prior to departure, and convoy driving time in a twenty-four hour period will not exceed twelve hours except in an emergency situation. All road mileages between installations and cities were obtained from AR 55-60/NAVSO P-2471/AFR 177-135 (1978). Weight (axle load) and dimension limits of motor vehicles resulting from state regulations were found in USAIC Regulation 55-1 (1976).

Other Sources

Several additional studies and publications were reviewed to obtain data for this thesis and an indication of the types of data considered relevant.

Hiatt, Gordon, and Oiesen (1976) developed a model to evaluate the functioning of an airport while processing a varied number and type of aircraft. The processing rate of the airport was a function of the weather, the mix of aircraft types, an arrival/departure ratio, and the separation time required between the types of aircraft. The available airbases in CONUS were selected from a list published in Air Force Magazine (Frisbee, 1978b). The number of active duty C130, C141, and C5 squadrons were obtained from the same periodical (Frisbee, 1978a).

Numerous computer based models for planning rail transportation have been derived such as the Southern Railway Flow Rule Model (Baker, 1977) which utilizes transit cost to allocate empty freight cars. The cost equation is composed of an average mileage cost, system-wide operation cost per car mile, average operation cost per car handled in a yard, origin to destination distance and time, opportunity frequency per week for moves from an origin to a destination, and the average time cost per day for a railcar. Folk (1972) developed a model to study rail time reliability where the maximum weight of a train was dictated by engine horsepower, track grade, speed, and weather. The train length in the study was limited to 120 cars. The locomotive weight utilized in this study was taken from a Southern Railway Company timetable (Southern Railway Company, 1977). Several reports concerning the federally funded Northeast Corridor Project were reviewed. Fourer (1976)

used two types of rail costs in his models: operating and switching. Prokopy and Ruina (1976) used a combination of gas, oil, and tire expenditure as the cost for automobile traffic. Peat, Marwick, Mitchell, and Company (1976) separated rail costs into several components: energy, car maintenance, crew cost, general overhead, passenger service, transportation, maintenance of equipment, and transportation department liability.

A simulation model for the movement of Army units in preparation for a long distance deployment was developed by Ortman and Parkinson where the preparation time for a vehicle to be loaded for the deployment included fueling, repairing, and travel time to the embarkation point. Hayes and Cutler (1976) formulated a simulation model to load Army units on aircraft for deployment. The model loaded the largest vehicle remaining on the waiting list that would fit in the storage space remaining in the aircraft.

A rail/truck competition model by Kullman (1973) viewed rail transportation as less reliable and slower than motor transportation but also less likely to cause cargo damage. Delays to motor operations were the result of equipment failure or congestion. Rail delays were caused by track congestion, equipment failure, lost waybills, misrouted cars and accidents. Terziev and Roberts (1976) developed similar models of rail/truck reliability. Most delays for carriers were sustained at terminals. Motor delays in pickup and delivery were found to be less than delays during transit. Delays in rail movements were caused by a lack of equipment available, unusable cars due to uncleanliness or damage, and car delivery to the incorrect location.

Rail pickup and delivery delays were caused by the failure to deliver a railcar for loading or a delay in the pickup of a loaded car for attachment to a train.

Piercy and Ballou (1978) studied 10,000 Department of Defense (DOD) and 6,000 industrial freight shipments to obtain an evaluation of freight carriers. The results of the study indicated that damages as a percentage of freight charges for air, rail, and motor carriers are: air - 0.2%, rail - 0.1%, motor - 0.7%. Each rail carrier interchange added .95 days and each motor carrier interchange added .65 days to the overall movement time.

Several models pointing out areas of concern for a war emergency have been formulated by Jack Faucent Associates (1976). Motor movement will be constrained by the availability of fuel and damaged highways will cause some problems but can be bypassed. Civil air facilities are vulnerable to enemy attack since air assets are concentrated there. Rail systems are susceptible to interdiction at classification yards and bridges where traffic is routed into a concentrated area.

The total number of Air Force aircraft available (C5 - 70, C141 - 234, C130 - 488) was obtained from the Proceedings of the 1977 Worldwide Strategic Mobility Conference (Moore, 1977), Air Force Magazine (Frisbee, 1978a), and Army (Ludvigsen, 1979). The dimensions and weight of the equipment to be transported were found in TB 55-46-1 (1978).

III. METHODOLOGY

The procedure followed in building the model is described in the following sections. The basic format of integer linear programming models and the branch and bound algorithm used to solve this problem are presented in the section titled Algorithm. The second section, Model, explains the model format derived for this thesis. The variables used to compute the solution are discussed in the final section, Data.

Algorithm

Integer programming models require the optimization (minimization or maximization) of a linear objective function subject to linear constraints. The objective function can be any linear function that assigns some type of weight to the value of the variables concerned. The constraints may be any linear combination of the variables to be determined that restrict the values of the variables. A general format is:

$$\text{(1)} \qquad \text{optimize} \quad \sum_{j=1}^{m} c_j x_j$$

subject to

$$\text{(2)} \qquad \sum_{j=1}^{m} a_{ij} x_j \leq b_i \quad \text{for } i = 1, 2, \ldots, n$$

$$\text{(3)} \qquad x_j \geq 0 \quad \text{for } j = 1, 2, \ldots, m$$

$$\text{(4)} \qquad x_j \text{ integer valued for } j = 1, 2, \ldots, q \ (\leq m).$$

The objective function and a linear constraint are illustrated by (1) and (2) respectively. The inequality sign could be reversed or be replaced by a strict equality. Equation (3) restricts the values of the variables to positive numbers or zero and (4) restricts the variables to only integer values. This is an extremely important constraint for transportation problems. The integer value requirement differentiates integer programming problems from standard linear programming problems and increases the computational effort required.

The branch and bound algorithm is a widely used technique for solving integer programming problems. The IBM Mixed Integer Programming/370 (MIP/370) package used to solve the model utilizes the branch and bound method. The algorithm's functioning is briefly described here and a more detailed explanation can be found in Wagner (1975).

The integer-valued variables are first provided lower and upper bounds that include the optimal values:

(5) $$L_j \leq x_j \leq U_j \quad \text{for } j = 1, 2, \ldots, p.$$

In many instances $L_j = 0$, but that condition is not mandatory. The branch and bound algorithm is based on the following concept. If I is an integer value where $L_j \leq I \leq U_j - 1$ and a variable x_j exists then an optimal solution to the general model presented including the bounding constraints will satisfy:

$$x_j \geq I + 1$$

or

$$x_j \leq I.$$

Suppose at any iteration t, a lower bound, x_o^t for the objective function optimal value exists. For simplicity, assume x_o^t is less than or equal to the objective function value for a feasible solution pre-

viously recorded. A master list of linear programming problems requiring solutions also exists which at the first iteration consists of equations structured as (1), (2), (3), and (5).

The procedural steps at iteration t are:

Step 1. Remove a linear programming problem from the master list or cease computations if the master list is empty.

Step 2. Solve the problem. If no feasible solution exists or the objective function x_o value is less than or equal to x_o^t, let $x_o^{t+1} = x_o^t$ then return to Step 1. Go to Step 3 otherwise.

Step 3. If the optimal solution meets the integer constraints, record it and use x_o^{t+1} as the optimal value for the objective function and go to Step 1. If not, go to Step 4.

Step 4. Select a variable x_j, for $j = 1, 2, \ldots, q$, without an integer value in the optimal solution of the linear programming problem used. Let b_j represent this value and (b_j) the largest integer that is less than or equal to b_j. Add two linear programming problems to the master list that are identical to the one chosen in Step 1 with the following exceptions: one problem must replace the lower bound on x_j with $(b_j) + 1$ and the other must replace the upper bound on x_j with (b_j). Set $x_o^{t+1} = x_o^t$ and go to Step 1.

If a feasible solution has been recorded at termination, the solution is optimal. Should this not be the case, no feasible solution exists. The procedure at Step 1 is termed "branching" while Step 2 is called "relaxation" (the linear programming problem is solved ignoring, or relaxing, the integer value constraint). "Fathoming" describes the process where further consideration of the problem is not necessary if the linear programming solution does not provide an objective function value greater than the current lower bound. Step 4 is called "separation" because a linear programming problem with an optimal objective function greater than the current lower bound provides two "descendants" (additional linear programming problems).

Model

After reviewing the literature discussed in Chapter 2 and conducting numerous interviews, a model to minimize the cost associated with the deployment of a field artillery battery in the Continental United States (CONUS) was developed. The objective function minimizes the cost associated with such a movement as related by the load plans utilized. A load plan is a list of the personnel and equipment moved by a particular carrier. The model is given below.

$$(6) \qquad \text{minimize} \quad \sum_{j=1}^{m} L_j C_j$$

subject to

$$(7) \qquad \sum_{j=1}^{m} E_{ij} L_j \geq N_i \quad \text{for } i = 1, 2, \ldots, x$$

(8) $$\sum_{j=n_k}^{n_{k+1}-1} L_j \leq A_k \quad \text{for } k = 1, 2, \ldots, z \quad (n_1 = 1,\ n_{z+1} = 16)$$

(9) $$\frac{\sum_{j=n_k}^{n_{k+1}-1} O_j L_j}{R_k} + \frac{\sum_{j=n_k}^{n_{k+1}-1} U_j L_j}{P_k} \leq T - M_k \quad \text{for } k = 1, 2, \ldots, z \quad (n_1 = 1,\ n_{z+1} = 16)$$

(10) $$\sum_{k=a}^{b} \sum_{j=n_k}^{n_{k+1}-1} L_j \leq F$$

(11) $$\sum_{k=a}^{b} \sum_{j=n_k}^{n_{k+1}-1} W_j L_j \leq S$$

(12) $$L_j \geq 0 \quad \text{for } j = 1, 2, \ldots, m$$

(13) $$L_j \text{ integer valued for } j = 1, 2, \ldots, q\ (\leq m)$$

The objective function is equation (6) where L_j represents the specific load plan utilized and C_j is the cost associated with each load plan. The variable m represents the maximum number of feasible load plans and must be determined prior to using the model. The number is directly related to the types of transport available and the equipment types requiring movement.

The requirement for the transportation of at least some minimum amount of equipment is depicted by (7). In other words, all of the unit's equipment and personnel must be transported. E_{ij} is the number of type i pieces of equipment that are included in load plan type j. N_i represents the number of E_i's requiring movement. The transportation of the unit equipment may be performed by aircraft, railcars, or trucks. Motor movement includes utilizing the unit's trucks or a supporting unit's trucks (such as a medium truck company). For this example, the

battery equipment was divided into ten types including personnel. The transportation of the battery's containers (CONEXs) which are normally utilized only in garrison was included to illustrate the use of containerized cargo. The CONEXs would not accompany the unit on an emergency deployment such as that required in the case of war. The value of i depends of the equipment combination (truck/trailer combinations, etc.) specified for the unit.

Equation (8) restricts the number of load plans to the number of carriers of a particular type k (A_k) that transport a particular load plan type. For example, twenty-five C130 aircraft load plans cannot be used if only twenty C130 aircraft are available. The carrier types (k) available for the deployment mission may vary with each situation.

The deployment time available is a critical aspect of any military transportation mission and is constrained in (9). T is the total time available for the deployment. M_k is the movement time required for each carrier type k to reach the destination and is composed of crew changing time, time lost due to line interchanges, time required for maintenance, preparation time, refueling time, the lead time required to obtain the carriers to be used, the deployment distance divided by the average speed, the distance from the unit motor pool to the loading point requiring motor transport divided by the average speed, and the distance from the unloading point to the destination requiring motor transport divided by the average speed. O_j is loading time and U_j is the unloading time for the equipment in load plan j. R_k and P_k are the number of loading and unloading spaces, respectively, that are available for carrier k.

Constraints (10) and (11) pertain only to rail transportation. The variables a and b ($a < b$, $a > 0$, $b > 0$) refer to the carrier type k's that are rail carriers. F restricts the total number of rail cars used to the maximum number allowed for a train. For an artillery battery, this would normally not be a problem. The constraint is included to indicate that this restriction must be considered for larger units and could be a factor for movements in a hostile environment. The weight of the rail load plans is restricted by the payload capacity (S) available. The formula for S was derived by combining several formulas concerning a locomotive's tractive effort in FM 55-20 (1974). The formula is

$$S = RE \left[.5 \left(\frac{\left[\frac{WD}{8} - \left(\frac{WE}{2{,}000} \right) (20) \right] WX}{RR + GR + CR} \right) \right] (2{,}000)$$

where

RE: the number of locomotives available

WD: the weight supported by the locomotive driving wheels (WD = WE for diesel-electric locomotives (House, 1979))

WE: locomotive weight

WX: weather factor indicating the percent of tractive effort actually utilized due to the weather encountered

RR: rolling resistance resulting from the friction between the railcar wheels and the track depending on the track condition

GR: grade resistance which results from the steepest grade that must be traversed along the route; computed by multiplying 20 times the grade in percent

CR: curve resistance resulting from the most severe curve that must be negotiated; computed by multiplying 0.8 times the curve in degrees.

Constraint (12) prevents a negative number of load plans from being generated. Constraint (13) requires only integer values be considered for the optimal solution. The assumptions required for the model are given below.

1. All troops are moving as equipped for combat; duffle bags, etc. are in vehicles or CONEXs.
2. All organizational equipment can be loaded in the unit's vehicles or CONEXs.
3. The time to load organizational and personal equipment in the unit's vehicles and containers is the same for all transportation modes used.
4. The time to prepare organizational equipment and vehicles is the same for all modes.
5. The time to assemble and brief the troops is the same for all modes.
6. The equipment and personnel to load and unload the unit are available at the required sites for each mode.
7. Political considerations do not preclude the use of any mode.
8. Security restrictions do not preclude the use of any mode.
9. Convoy, train, and flight size is not considered as the movement planners could combine the assets used in any configuration required.

There are several factors not included in the model formulation which must also be considered. All routes must be investigated to in-

sure that bridge capacity, highway width, highway weight restrictions, personnel considerations (feeding capability, sanitation facilities, sleeping facilities, etc.), refueling points, and runway lengths do not prevent the utilization of a particular carrier type. Additionally, aircraft floor strength and center of gravity limits must be considered in determining aircraft load plans. Cargo compartment dimensions (height, length, and width) and payload limits must be considered for all carrier types. Height is critical even for rail flatcars when tunnels or other overhead obstacles such as wires are considered.

Data

The units of measurement used are:

cost	-	dollars
distance	-	miles
time	-	hours
weight	-	pounds
grade	-	percent
curve	-	degrees

The initial step in preparing the data for the model was to ascertain the equipment types found in a field artillery battery at Fort Benning, GA. For this example, a 105mm howitzer battery will be used. The equipment requiring transportation was obtained from the Table of Organization and Equipment (TOE) for such a unit stationed at Fort Benning (MTOE 06185HFC11 FC 1079, 1978). The equipment models and pairings (truck/trailer, etc.) were determined after consulting personnel in the parent units (battalion and brigade) of the battery (Donahue, 1979; Graham, 1979). The equipment types used to generate feasible load plans

are listed in Table 1. Prime movers were combined with the appropriate trailer or howitzer to insure that no piece of equipment would be transported to some point and then lack motive power.

Table 1

Equipment Types

Variable	Description	Number	Weight (lb.)
E_1	Personnel with combat equipment	87	240
E_2	CONEX	6	10,500
E_3	M561 $1\frac{1}{4}$ Ton Truck	1	8,540
E_4	M561 $1\frac{1}{4}$ Ton Truck, M101A1 3/4 Ton Trailer	1	11,390
E_5	M35A2 $2\frac{1}{2}$ Ton Truck (without winch), M332 Ammunition Trailer	2	23,700
E_6	M35A2 $2\frac{1}{2}$ Ton Truck (without winch), M149 Water Tank Trailer	1	21,657
E_7	M35A2 $2\frac{1}{2}$ Ton Truck (without winch), M105A2 $1\frac{1}{2}$ Ton Trailer	1	21,450
E_8	M35A2 $2\frac{1}{2}$ Ton Truck (with winch), M101A1 105mm Howitzer	6	21,050
E_9	M35A2 $2\frac{1}{2}$ Ton Truck (with winch)	1	16,170
E_{10}	M151A2 $\frac{1}{4}$ Ton Truck	1	2,530

Load plans were generated by preparing floor diagrams for the carrier vehicles and two dimensional models of the equipment types then manually arranging the equipment outlines to fill the cargo compartments without exceeding the payload and height limitations. Equipment dimensions and the aircraft capable of transporting the equipment types

were found in TB 55-46-1 (1978). Aircraft cargo compartment dimensions, performance characteristics, floor diagrams, and example load plans were obtained from the field manuals and technical manuals previously referenced. Defense Freight Railway Interchange Fleet (DFRIF) railcar dimensions and weight capacity were provided by Clarence Edwards (1979) at MTMC in Bayonne, NJ. The capacity of the M52A1 5 Ton Tractor Truck and the M127A1 12 Ton Stake Semitrailer used for CONEX motor movement in this example was provided by LT Marianne Hook (1979) of the 533d Medium Truck Company. The load plans are provided in Appendix A. Table 2 lists the carrier types and their corresponding load plans.

The transportation costs for the three Air Force aircraft used here (C130, C141, and C5) were obtained from the Military Traffic Management Command (MTMC) in Washington, D.C. (Beck, 1979). Rail movement rates were obtained through the Columbus, GA, office of the Southern Railway Company (Bingham and Redmond, 1979a). Motor costs were computed by combining expected tire wear, fuel usage, lubricant usage, and repair parts expenditures for the trucks, trailers, and howitzers based on the experiences of individuals involved in such operations (Files, 1979a and 1979b; Hook, 1979). The cost figures determined are listed in Appendix B. An expected dollar expenditure for damages expressed as a percent of freight charges was used to modify the original cost values to reflect expected damage (Piercy and Ballou, 1978). The damage percentages are listed in Appendix B.

The number of aircraft available in this example are assumed. The figure would vary from day to day depending on previous unit taskings and the priority of the mission concerned. The numbers used are: C130 - 30, C141 - 25, and C5 - 15. The maximum number of aircraft avail-

Table 2

Carrier Types and Load Plans

k	Carrier	Load Plans
1	C130	L_1 to L_{12}
2	C141	L_{13} to L_{36}
3	C5	L_{37} to L_{50}
4	M561 $1\frac{1}{4}$ Ton Truck	L_{51}
5	M561 $1\frac{1}{4}$ Ton Truck with M101A1 3/4 Ton Trailer	L_{52}
6	M35A2 $2\frac{1}{2}$ Ton Truck with M332 Ammunition Trailer	L_{53}
7	M35A2 $2\frac{1}{2}$ Ton Truck with M149 Water Trailer	L_{54}
8	M35A2 $2\frac{1}{2}$ Ton Truck with M105A2 $1\frac{1}{2}$ Ton Trailer	L_{55}
9	M35A2 $2\frac{1}{2}$ Ton Truck with M101A1 105mm Howitzer	L_{56}
10	M35A2 $2\frac{1}{2}$ Ton Truck	L_{57}
11	M151A2 $\frac{1}{4}$ Ton Truck	L_{58}
12	M52A1 5 Ton Tractor Truck with M127A1 12 Ton Stake Semitrailer	L_{59}
13	54 ft x 10 ft 6 in Flatcar	L_{60} to L_{86}
14	50 ft x 10 ft 6 in Flatcar	L_{87} to L_{106}
15	Guard Car	L_{107} to L_{114}

able could include the entire active duty air fleet: C130 - 488, C141 - 234, C5 - 70 (Frisbee, 1978a; Ludvigsen, 1979; Moore, 1977). The motor carriers available are limited by the trucks to be moved, except for the CONEXs, since each truck can transport itself and a trailer or howitzer. Sixty tractor/semitrailers of the type used to move the CONEXs are found in a medium truck company. The vehicles are also found in separate brigades and divisions. A separate medium truck company is located at

Fort Benning but is in an administrative storage status meaning it is not normally tasked with providing support for such a movement (Hook, 1979). Three tractor/semitrailers will be assumed available. Fort Benning usually has a total of thirty-five DOD owned flatcars available belonging to the DFRIF. Additional cars can be obtained if time permits (Roland and Porter, 1979). Ten fifty foot flatcars, twenty-five fifty-four foot flatcars, and ten guard cars are assumed available for this movement. Each guard car can carry up to nine personnel (Donahue, 1979).

The loading and unloading times for aircraft were determined after reviewing the previously referenced manuals on standard loads and discussing the problem with CPT David Lawrence (1979a) of the 317th Tactical Air Wing located at Fort Benning. No specific data on the time required to load and tiedown or unload an individual piece of equipment could be found; therefore, all times are approximate. CPT Lawrence (1979b) also provided the number of parking spaces for aircraft at Lawson Field, the departure point for air movement from Fort Benning. The unloading spaces at Charleston Air Force Base (AFB), SC, and Travis AFB, CA, (the air movement destination airfields) are assumed the same as those at Lawson.

Rail loading and unloading times were approximated based on the recent experiences of the 197th Infantry Brigade's deployment to Fort Drum, NY (Slater, 1979). The loading ramps available were designated through the ITO at Fort Benning (Roland and Porter, 1979). Only the five end loading ramps at the main post location will be assumed available for loading. Other ramps are available in a different location but are seldom used (House, 1979). Four loading spaces are assumed

available for the guard cars since all that is required is a track space large enough to accomodate the cars. The unit's motor carrier load times are actually the approximate times required to complete filling the vehicle fuel tanks which are normally three-quarters full when the vehicle is to be transported. Loading personnel and equipment was not used since that is required for any type of movement to be conducted. The refueling times were compiled after discussions with several individuals at Fort Benning (Files, 1979a; Hook, 1979; Pate and King, 1979). Approximately thirty minutes is required to load or unload a CONEX (Pate and King, 1979).

The loading and unloading times for each load plan are listed in Table 3. The loading and unloading spaces for each carrier type are listed in Table 4.

Three maximum deployment times (T values) are used for illustrating the model functioning: three, seven, and thirty days. The movement time (M_k) values are the combination of several elements. Air distances were provided by CPT Lawrence (1979a). Motor distances were obtained from AR 55-60/NAVSO P-2471/AFR 177-135 (1978). Rail distances were provided by the Southern Railway's Columbus Office (Bingham and Redmond, 1979a). Air speeds are listed in TM 55-450-15 (1971). Example motor speeds can be found in FM 55-30 (1974). MTMC, Eastern Area uses 45 mph for motor convoys traveling on twenty-four hour operations (Hanson, 1979a). An average rail speed of 25 mph was obtained through the Southern Railway (House, 1979).

The deployment scenarios involve movement to Charleston, SC, or San Francisco, CA. Since the mode routes do not terminate in the same

Table 3

Loading/Unloading Times

Load Plan	Load Time	Unload Time	Load Plan	Load Time	Unload Time	Load Plan	Load Time	Unload Time	Load Plan	Load Time	Unload Time
1	.42	.17	30	1.28	.40	59	1.00	1.00	88	3.00	3.00
2	.42	.17	31	1.00	.32	60	1.25	1.25	89	3.50	3.50
3	.42	.17	32	1.58	1.20	61	3.00	3.00	90	3.00	3.00
4	.42	.17	33	.72	.25	62	1.25	1.25	91	2.50	2.50
5	.42	.17	34	2.50	2.50	63	3.00	3.00	92	2.00	2.00
6	.67	.25	35	2.08	2.08	64	1.25	1.25	93	1.25	1.25
7	.92	.67	36	.17	.17	65	1.75	1.75	94	1.25	1.25
8	.33	.17	37	2.25	.42	66	1.25	1.25	95	1.25	1.25
9	.58	.25	38	2.03	.40	67	1.25	1.25	96	1.25	1.25
10	1.25	1.08	39	2.39	.45	68	1.75	1.75	97	2.00	2.00
11	1.08	1.08	40	2.25	.68	69	2.00	2.00	98	1.25	1.25
12	.17	.17	41	2.25	.42	70	2.00	2.00	99	1.75	1.75
13	.78	.28	42	2.03	.40	71	2.50	2.50	100	2.50	2.50
14	.86	.28	43	2.39	.45	72	1.25	1.25	101	2.00	2.00
15	.78	.28	44	2.25	.77	73	1.75	1.75	102	2.75	2.75
16	1.50	1.20	45	2.03	.40	74	1.75	1.75	103	2.25	2.25
17	.78	.28	46	2.25	.28	75	2.50	2.50	104	2.75	2.75
18	.86	.28	47	2.53	.33	76	2.00	2.00	105	2.25	2.25
19	.78	.28	48	2.83	.93	77	2.75	2.75	106	1.75	1.75
20	1.50	1.20	49	3.78	3.13	78	2.25	2.25	107	.16	.16
21	.50	.20	50	4.14	2.80	79	3.25	3.25	108	.16	.16
22	.86	.28	51	.10	.08	80	2.75	2.75	109	.16	.16
23	.78	.28	52	.10	.08	81	2.25	2.25	110	.16	.16
24	1.50	1.20	53	.11	.13	82	1.75	1.75	111	.16	.16
25	.78	.28	54	.11	.13	83	3.50	3.50	112	.16	.16
26	.86	.28	55	.11	.13	84	3.00	3.00	113	.16	.16
27	.78	.28	56	.11	.13	85	2.50	2.50	114	.16	.16
28	1.50	1.20	57	.11	.13	86	2.00	2.00			
29	.86	.28	58	.10	.08	87	1.25	1.25			

Table 4

Loading/Unloading Spaces

k	Fort Benning	Charleston	San Francisco
1	8	8	8
2	5	5	5
3	3	3	3
4	1	1	1
5	1	1	1
6	2	2	2
7	1	1	1
8	1	1	1
9	6	6	6
10	1	1	1
11	1	1	1
12	1	1	1
13	5	5	5
14	5	5	5
15	4	4	4

location, some interface via motor transport is required. The motor distances are those from the main entrance of the installation or the geographic point in the city normally used for distance measurement to the same type of point at the destination (AR 55-60/NAVSO P-2471/AFR 177-135, 1978). The end point of the motor route is considered the final destination; therefore, motor movement is required from the destination rail terminal and airfield. Figure 3 illustrates the

routes used. Mileages between the motor pool and the three start points were determined by personal measurement. The mileages at the destinations between the railheads and the cities are assumed to be the values listed.

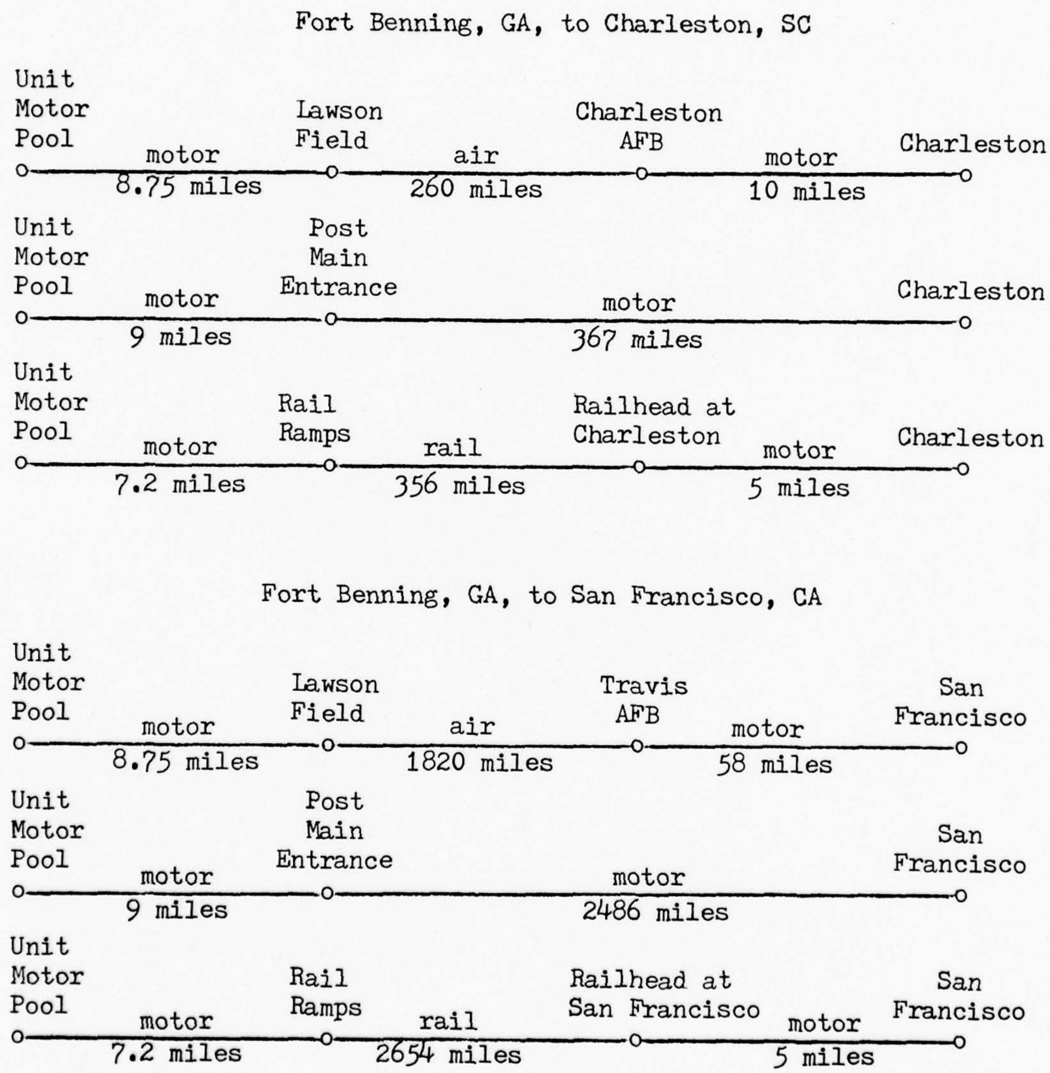

Figure 3

Movement Routes

Time required to change crews affects the motor portion of this study. The short distances and high speeds of air transport preclude the need for changing air crews (Lawrence, 1979a). The rail average speed includes changing crews. The motor crew changing time includes rest stops which are fifteen minutes at the end of the first hour and ten minutes every two hours thereafter. Thirty minutes are required for meal halts (AR 55-29, 1971). The computations of the motor crew changing, maintenance, and refueling times are presented in Appendix C. Planning figures for Appendix C were obtained through the 197th Infantry Brigade (Files, 1979a).

The only line interchange existing in either scenario is at New Orleans, LA, for the rail mode in the San Francisco movement. The interchange is between the Southern and the Southern Pacific lines. This results in 22.8 hours (24 x .95) being included in the movement time.

No additional preparation or refueling time at the loading point is necessary for the Air Force aircraft since the constraining time is that required for loading (Lawrence, 1979a). The time to obtain the aircraft depends on their location and preparation status when alerted for the mission. If the C130 aircraft utilized are stationed at Pope AFB, NC, and an alert crew is used, the aircraft can arrive at Lawson in four hours. This is the sum of a 2.25 hour reaction time for the crew and a 1.75 hour flight. C141 aircraft stationed at Charleston AFB, SC, can fly to Lawson in three hours which includes the same crew reaction time and a .75 hour flight (Lawrence, 1979a). C5 aircraft flying from Dover AFB, DE, can arrive in 4.91 hours: $\frac{620 \text{ miles}}{440 \text{ mph}} + 3.5$ hour reaction time for crew (Aiken, 1979).

No additional preparation time for the unit's vehicles is included since the equipment requiring transport is composed of those same vehicles. A preparation time of .58 hours for the tractor/semitrailer results from .25 hours necessary to prepare the vehicle for movement and approximately .33 hours required to drive to the battery motor pool (Hook, 1979). Twelve hours is included as the time to obtain the unit's vehicles to provide for the rest dictated by regulation (AR 55-29, 1971). Twenty-four hour advance notice would be required to obtain the tractor/semitrailers from a supporting medium truck company (Hook, 1979).

A four hour preparation time for the rail locomotives is derived from a three hour preparation time (FM 55-20, 1974) and one hour to move the locomotives to the loading area (House, 1979). If the situation dictated prompt action, the DOD owned flatcars at the installation could be prepared and released for use in twenty-four hours (Roland, 1979). Tables 5 and 6 illustrate the appropriate time values for the Charleston and San Francisco routes.

The maximum number of railcars allowed would vary between railroads depending on the situation. The figure of 150 used here can be exceeded with special permission from the chief dispatcher at the railhead (House, 1979). The total weight of the equipment moving by rail depends on the factors mentioned in the discussion of locomotive tractive effort. Four General Purpose type engines would probably be available for a move such as this one (Banks, 1979). A weight of 272,000 pounds will be used for this example (Southern Railway Company, 1977). The worst temperatures encountered on the routes are a possible

Table 5

Movement Time Values - Charleston

k	DI/SP +	OD/OS +	UD/US +	CC +	LX +	MT +	PR +	RF +	TA =	M_k
1	$\frac{260}{280}$	$\frac{8.75}{15}$	$\frac{10}{15}$	0	0	0	0	0	4	6.18
2	$\frac{260}{440}$	$\frac{8.75}{15}$	$\frac{10}{15}$	0	0	0	0	0	3	4.84
3	$\frac{260}{440}$	$\frac{8.75}{15}$	$\frac{10}{15}$	0	0	0	0	0	4.91	6.75
4	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
5	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
6	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
7	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
8	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
9	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
10	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
11	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	0	.5	12	25.55
12	$\frac{367}{45}$	$\frac{9}{15}$	0	.75	0	3.54	.58	.5	24	38.13
13	$\frac{356}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	0	0	4	0	24	43.05
14	$\frac{356}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	0	0	4	0	24	43.05
15	$\frac{356}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	0	0	4	0	24	43.05

k: carrier type
DI: distance
SP: average speed
CC: crew changing time
MT: maintenance time
PR: preparation time
RF: refueling time
OD: distance to loading point
OS: speed moving to loading point
UD: unloading point to destination distance
US: unloading point to destination speed
LX: line interchange time
TA: lead time to obtain the carrier
M_k: movement time

Table 6

Movement Time Values - San Francisco

k	DI/SP +	OD/OS +	UD/US +	CC +	LX +	MT +	PR +	RF +	TA =	M_k
1	$\frac{1820}{280}$	$\frac{8.75}{15}$	$\frac{58}{20}$	0	0	0	0	0	4	13.98
2	$\frac{1820}{440}$	$\frac{8.75}{15}$	$\frac{58}{20}$	0	0	0	0	0	3	10.62
3	$\frac{1820}{440}$	$\frac{8.75}{15}$	$\frac{58}{20}$	0	0	0	0	0	4.91	12.53
4	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
5	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
6	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
7	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
8	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
9	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
10	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
11	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	0	2.83	12	99.75
12	$\frac{2486}{45}$	$\frac{9}{15}$	0	5.08	0	24	.58	2.83	24	112.33
13	$\frac{2654}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	22.8	0	4	1	24	158.77
14	$\frac{2654}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	22.8	0	4	1	24	158.77
15	$\frac{2654}{25}$	$\frac{7.2}{15}$	$\frac{5}{15}$	0	22.8	0	4	1	24	158.77

k: carrier type
DI: distance
SP: average speed
CC: crew changing time
MT: maintenance time
PR: preparation time
RF: refueling time
OD: distance to loading point
OS: speed moving to loading point
UD: unloading point to destination distance
US: unloading point to destination speed
LX: line interchange time
TA: lead time to obtain the carrier
M_k: movement time

$-9^{\circ}F$ in Atlanta, GA, and $-8^{\circ}F$ in El Paso, TX, (U.S., Department of Commerce, 1969) which correspond to a weather factor of 0.85 (FM 55-20, 1974). The track condition on the Charleston route can be generally classified as exceptionally good and on the San Francisco route as good (Bingham and Redmond, 1979b). This corresponds to rolling resistance values of five and six respectively (FM 55-20, 1974). The worst grade on the Charleston route is 1.25% at Aiken, SC (Wolf, 1979). The worst grade on the San Francisco route that could be determined is 1.2% at Sterret, AL (House, 1979). These grades result in grade resistance values of twenty-five and twenty-four respectively. A severe 10° curve is found on the San Francisco route near Opelika, AL, which necessitates a curve resistance value of eight (House, 1979). No restrictive curves are encountered on the Charleston route (Wolf, 1979). Table 7 provides the tractive effort computations limiting the rail payload.

Appendix D provides a listing of the computer program utilized to solve the model for a movement to San Francisco allowing all three modes with a maximum deployment time of seven days.

Table 7

Rail Payload Constraint

$$\text{Payload} \leq \text{RE}\left[.5\left(\frac{\left[\frac{WD}{8} - \left(\frac{WE}{2{,}000}\right)(20)\right] WX}{RR + GR + CR}\right)\right](2{,}000)$$

<u>Charleston</u>

$$\text{Payload} \leq 4\left[.5\left(\frac{\left[\frac{272{,}000}{8} - \left(\frac{272{,}000}{2{,}000}\right)(20)\right] .85}{5 + (1.25)(20) + 0}\right)\right](2{,}000)$$

$$\leq 3{,}545{,}066.6 \text{ pounds}$$

<u>San Francisco</u>

$$\text{Payload} \leq 4\left[.5\left(\frac{\left[\frac{272{,}000}{8} - \left(\frac{272{,}000}{2{,}000}\right)(20)\right] .85}{6 + (1.2)(20) + (10)(.8)}\right)\right](2{,}000)$$

$$\leq 2{,}798{,}736.8 \text{ pounds}$$

IV. RESULTS

Optimal solutions obtained and a sensitivity analysis of each under various conditions will be discussed in this chapter. The chapter is divided into two major sections: the first explaining the optimal solutions to Charleston using various modes of travel and the second discussing the minimum cost solutions to San Francisco. Subheadings differentiate between the mode selections allowed.

Charleston

Air, Motor, and Rail

The integer linear model initially determined the least cost mix of transportation assets required to move a field artillery battery from Fort Benning, GA, to Charleston, SC, given a maximum of three days for deployment. Deployment times exclude the unit planning process required (such as unit assembly time, issue of the operations order, etc.) which is assumed the same regardless of the mode chosen. The feasible load plans generated and the range of cost values for which valid are listed in Table 8. The feasible load plans are those determined to provide the least cost means of transporting the battery. Note that the majority of the equipment will move under its own power. The M151A2 Truck and the six CONEXs will utilize a fifty foot flatcar. This solution minimizes the cost but might not be preferred by the battery commander because the M151A2 is his vehicle. The commander may want to use

the M151A2 to assist in controlling the convoy and to prevent the battery headquarters element using a vehicle that is the responsibility of another battery section. Obviously, rail motive power is not a limiting factor in this solution. The one flatcar would be incorporated in a train moving to Charleston. This could slightly alter the movement time required because the times computed for the model were based on planning factors for a unit train composed of railcars loaded with the battery equipment. The load plans selected provide for the movement of 102 personnel. This exceeds the total personnel in the battery, eighty-seven, by fifteen. Therefore, fifteen additional troops could be carried without affecting the optimal solution.

The objective function value of $2,365.28 is the total cost of the deployment using the load plans in the optimal solution. The cost ranges provided for the load plans indicate the range of values the load plan costs can vary within and not change the optimal solution. In other words, the cost associated with the M561 Truck for L51 can take any value up to $105.77 without L51 leaving the optimal solution.

The marginal costs, or addition to the objective function value for an increase of one item, by equipment type are listed in Table 9. For example, the addition of one M35A2 Truck and M332 Trailer (E_5) will increase the cost of this movement by $129.36. The marginal costs given in the table are only valid for the values of the variables in this solution. This holds for every discussed scenario. Should more equipment be included and a new optimal solution generated, new marginal costs will be derived.

The load plans selected for the optimal solution remained unchanged when the time constraint was increased from a maximum of three

days to seven days and again to thirty days. Motor transportation is the best mode for deploying the majority of the equipment due to its low cost for the distance traveled. L89, the flatcar, will remain in the optimal solution as long as the maximum deployment time allowed does not decrease below 44.45 hours. This figure results from a rail movement time of 43.05 hours and a loading/unloading time of 1.40 hours as calculated by the model constraints. One L58 and three L59s will enter the solution to transport the M151A2 and the CONEXs respectively if time forces out L89. If the deployment time decreased to the point where the trucks could not reach Charleston in time, aircraft would be required. This point varies with each type of motor carrier and is computed as illustrated above. The appropriate values for the motor carriers under these conditions are given below.

Minimum Deployment Time (hours)	Carrier
25.73	M561 Truck
25.73	M561 Truck, M101A1 Trailer
26.03	M35A2 Truck, M332 Trailer
25.79	M35A2 Truck, M149 Trailer
25.79	M35A2 Truck, M105A2 Trailer
26.99	M35A2 Truck, M101A1 Howitzer
25.79	M35A2 Truck
25.73	M151A2 Truck
41.13	M52A1 5 Ton Tractor Truck, M127A1 12 Ton Stake Semitrailer

Table 8

Optimal Solution - Charleston - Air, Motor, Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L51	1	M561 Truck	M561 Truck, 6 Troops	$ 0	$105.77
L52	1	M561 Truck	M561 Truck, M101A1 Trailer, 6 Troops	0	Infinity
L53	2	M35A2 Truck	M35A2 Truck, M332 Trailer, 2 Troops	0	Infinity
L54	1	M35A2 Truck	M35A2 Truck, M149 Trailer, 10 Troops	0	Infinity
L55	1	M35A2 Truck	M35A2 Truck, M105A2 Trailer, 10 Troops	0	Infinity
L56	6	M35A2 Truck	M35A2 Truck, M101A1 Howitzer, 10 Troops	0	Infinity
L57	1	M35A2 Truck	M35A2 Truck, 6 Troops	0	Infinity
L89	1	50 Foot Flatcar	M151A2 Truck, 6 CONEXs	56.99	794.63

Air

After the initial solution which allowed any combination of the use of three transportation modes was obtained, the model determined the least cost load plans assuming only one carrier mode available at a time. The result of this procedure using air transport follows.

A feasible solution was obtained using four C130 and six C141 aircraft with a total cost of $33,210.28 and a maximum deployment time of three days. Load plans selected and the cost ranges for which valid are listed in Table 10. Capacity for ten troops above the number assigned to the battery is provided by the optimal solution. Deployment times of seven and thirty days did not change the optimal solution.

Marginal costs for the various equipment types are listed in Table 9. The minimum deployment time required disregarding loading and unloading time for the three aircraft types considered are: C130 - 6.18 hours, C141 - 4.84 hours, and C5 - 6.75 hours.

Table 9

Marginal Cost Data - Charleston

			Marginal Costs	
Equipment Types	Equipment in Each Type	Air, Motor, Rail	Air	Rail
E_1	Personnel	\$ 0	\$ 0	\$110.18* 100.31** 92.90***
E_2	CONEX	119.53	698.39	0
E_3	M561 Truck	105.78	1,396.78	327.34
E_4	M561 Truck, M101A1 Trailer	98.60	310.60	321.50
E_5	M35A2 Truck, M332 Trailer	129.36	2,482.96	341.43
E_6	M35A2 Truck, M149 Trailer	129.36	2,482.96	409.34
E_7	M35A2 Truck, M105A2 Trailer	129.36	2,482.96	407.06
E_8	M35A2 Truck, M101A1 Howitzer	125.89	2,482.96	402.65
E_9	M35A2 Truck	124.20	1,396.78	0
E_{10}	M151A2 Truck	56.99	1,086.18	0

*Solution 1
**Solution 2
***Solution 3

Table 10

Optimal Solution - Charleston - Air

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L1	3	C130	M35A2 Truck, M101A1 Howitzer, 16 Troops	$1,453.77	$2,694.96
L2	1	C130	M35A2 Truck, M149 Trailer, 13 Troops	129.36	2,694.96
L14	1	C141	M35A2 Truck, M101A1 Howitzer, M561 Truck, 6 Troops	2,578.50	Infinity
L16	2	C141	M35A2 Truck, M101A1 Howitzer, 2 CONEXs, 6 Troops	3,667.74	4,908.93
L21	1	C141	2 M35A2 Trucks, M332 Trailer, 4 Troops	1,526.14	4,091.74
L28	1	C141	M35A2 Truck, M105A2 Trailer, 2 CONEXs, 8 Troops	1,526.14	Infinity
L30	1	C141	M35A2 Truck, M561 Truck, M151A2 Truck, M101A1 Trailer, M332 Trailer, 6 Troops	3,667.74	Infinity

Motor

The solution given motor assets does not require calculation by a computer since motor load plans involve each truck moving itself with the associated trailer or howitzer for the corresponding equipment type. Capacity exists in the unit's vehicles to transport the full complement of personnel as illustrated by the excess capacity in the model solution allowing all three modes. The only vehicles outside the battery required are three M52A1 5 Ton Trucks with M127A1 12 Ton Semi-trailers to carry the CONEXs (two per vehicle). The cost follows.

M561 Truck	$ 95.54
M561 Truck with M101A1 Trailer	98.60
Two M35A2 Trucks with M332 Trailers	258.72
M35A2 Truck with M149 Trailer	129.36
M35A2 Truck with M105A2 Trailer	129.36
Six M35A2 Trucks with M101A1 Howitzer	755.34
M35A2 Truck	124.20
M151A2 Truck	56.99
Three M52A1 5 Ton Tractors with M127A1 12 Ton Semitrailers	765.96
Total Cost	$2,414.07

Rail

Three alternate optimal solutions exist for a rail scenario. Minimum cost for each of the three load plan mixes is $12,283.25. Differences result from the three possible configurations for moving the personnel in guard cars. Load plans selected to transport unit equipment minus personnel, which were identical for all three solutions, are listed in Table 11. Load plans for moving the troops associated with each solution are presented in Table 12. The range of cost values for the feasible load plans are given in the corresponding table. Varying deployment times (three, seven, and thirty days), as before, did not alter the optimal solution. Marginal costs by equipment type are listed in Table 9.

As a result of the duplication of load plans and freight charges between the two types of flatcars, other optimal solutions could be obtained. The following list denotes the load plans that are exact substitutes for those chosen in the optimal solution.

Table 11

Optimal Solution (Equipment Minus Personnel) - Charleston - Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L60	6	54 ft Flatcar	M35A2 Truck, M101A1 Howitzer, CONEX	$ 0	$Infinity
L64	2	54 ft Flatcar	M35A2 Truck, M332 Trailer, M151A2 Truck	0	Infinity
L67	1	54 ft Flatcar	M35A2 Truck, M149 Trailer, CONEX	0	Infinity
L69	1	54 ft Flatcar	M561 Truck, M101A1 Trailer, M151A2 Truck, CONEX	0	Infinity
L72	1	54 ft Flatcar	M561 Truck, M35A2 Truck	0	Infinity
L96	1	50 ft Flatcar	M35A2 Truck, M105A2 Trailer, CONEX	0	Infinity

Table 12

Optimal Solutions (Personnel) - Charleston - Rail

Solution Number	Load Plan	Number Required	Carrier	Personnel in Load Plan	Lower Cost[a]	Upper Cost
1	L111	1	Guard Car	6	.....	.....
1	L114	9	Guard Car	9	.....	.....
2	L113	3	Guard Car	8	.....	.....
2	L114	7	Guard Car	9	.....	.....
3	L112	1	Guard Car	7	$271.57	$Infinity
3	L113	1	Guard Car	8	0	802.45
3	L114	8	Guard Car	9	0	902.75

[a]The software package only provided data for the third solution.

Solution	Substitute
L60	L87
L64	L93
L67	L95
L72	L98
L96	L62

Excess capacity for three CONEXs and two M151A2 Trucks resulted from the load plans being generated manually with a minimum weight limit imposed to exceed the minimum weight for the applicable freight charge. If all feasible load plans could be generated through some means such as a simulation program, the actual freight charge for these rail load plans could be decreased. This, in turn, would decrease the total cost derived.

San Francisco

Air, Motor, Rail

Required deployment time to San Francisco, CA, precluded the consideration of all three modes with three days allowed. Seven days is sufficient. Solutions given seven days and thirty days were identical. All battery vehicles would travel under their own power with their respective loads except for the six CONEXs which would travel on three M52A1 5 Ton Tractor Trucks with M127A1 12 Ton Stake Semitrailers. Minimum deployment times affecting the load plans selected in the minimum cost solution and the rail load plan required if the tractor/ semitrailers were not available follow.

Minimum Deployment Time (hours)	Load Plan
99.93	L51
99.93	L52
100.23	L53
99.99	L54
99.99	L55
101.19	L56
99.99	L57
99.93	L58
115.33	L59
160.17	L89

Cost for the movement would be $26,587.75. Load plans and their cost ranges are provided in Table 13. An excess capacity for nineteen troops exists. Marginal costs for the equipment types are listed in Table 14.

Though motor may be the least expensive mode for this situation, the difficulties encountered in convoying a unit 2,486 miles would be enormous. Utilizing the unit's organic vehicles for such a lengthy move could adversely affect the unit's ability to perform its assigned mission at the destination due to wear and tear on the vehicles and personnel fatigue problems. Maintaining control over a vehicle convoy would be difficult for such a long distance due to personnel fatigue, accidents, maintenance problems, individual driving habits making a constant speed difficult to maintain, and local traffic control techniques. Even a device as commonplace as a traffic light could disrupt a convoy if it is not timed so that the entire convoy can pass at one time through the intersection that the light regulates. A potential problem area would

Table 13

Optimal Solution - San Francisco - Air, Motor, Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L51	1	M561 Truck	M561 Truck, 6 Troops	$ 0	Infinity
L52	1	M561 Truck	M561 Truck, M101A1 Trailer, 6 Troops	0	Infinity
L53	2	M35A2 Truck	M35A2 Truck, M332 Trailer, 2 Troops	0	Infinity
L54	1	M35A2 Truck	M35A2 Truck, M149 Trailer, 10 Troops	0	Infinity
L55	1	M35A2 Truck	M35A2 Truck, M105A2 Trailer, 10 Troops	0	Infinity
L56	6	M35A2 Truck	M35A2 Truck, M101A1 Howitzer, 10 Troops	0	Infinity
L57	1	M35A2 Truck	M35A2 Truck, 6 Troops	0	Infinity
L58	1	M151A2 Truck	M151A2 Truck, 4 Troops	0	Infinity
L59	3	M52A1 Truck, M127A1 Semi-trailer	2 CONEXs	0	Infinity

be the forced interaction with civilian personnel and property. If the area being traversed has an anti-military element, problems could result. Property damage caused by the unit personnel or equipment could disrupt the mission. Routing may pose a problem because the unit must insure eating facilities are provided. Civilian facilities could be used but few would be prepared to accomodate eighty-seven troops without prior warning. Facilities for sleeping must also be provided if the convoy will not travel on a twenty-four hour basis. Therefore, MTMC does not normally allow a military convoy over 700 miles (Hansen, 1979b). This prompted the deletion of the truck mode and the subsequent solution.

Table 14

Marginal Cost Data - San Francisco

		Marginal Costs			Rail	
Equipment Types	Equipment in Each Type	Air, Motor, Rail	Air, Rail	Air	7 Days	30 Days
E_1	Personnel	$ 0	$ 0	$ 0	$762.79	$762.79
E_2	CONEX	593.72	0	4,163.81	0	0
E_3	M561 Truck	1,035.89	1,035.89	8,327.62	3,465.55	0
E_4	M561 Truck, M101A1 Trailer	1,057.69	3,799.91	6,408.29	3,799.91	3,799.91
E_5	M35A2 Truck, M332 Trailer	1,854.29	4,012.25	10,572.10	4,012.25	4,012.25
E_6	M35A2 Truck, M149 Trailer	1,854.29	3,772.57	10,572.10	3,772.57	3,772.57
E_7	M35A2 Truck, M105A2 Trailer	1,854.29	3,748.28	10,572.10	3,748.28	3,748.28
E_8	M35A2 Truck, M101A1 Howitzer	1,838.09	3,701.36	10,572.10	3,701.36	3,701.36
E_9	M35A2 Truck	1,817.42	3,094.85	8,327.62	665.19	4,130.74
E_{10}	M151A2 Truck	668.76	268.66	2,244.48	268.66	268.66

Air, Rail

The solution given a seven day maximum deployment time allowing air and rail carriers is to move the personnel by air and the unit equipment by rail. This assumes that the unit commander relinguishes his equipment to the rail carrier without accompanying guard personnel. Circumstances might not allow this. The movement cost is $64,852.54. Table 15 provides the load plans selected and Table 14 lists the marginal costs. Increasing the deployment time to thirty days did not affect

Table 15

Optimal Solution - San Francisco - Air, Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L36	1	C141	100 Troops	$ 0	$Infinity
L65	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, M151A2 Truck, CONEX	4,012.25	Infinity
L66	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, CONEX	1,854.29	4,280.91
L67	1	54 ft Flatcar	M35A2 Truck, M149 Trailer, CONEX	1,854.29	Infinity
L70	1	54 ft Flatcar	M561 Truck, M101A1 Trailer, 2 CONEXs	1,057.69	Infinity
L74	1	54 ft Flatcar	M561 Truck, M35A2 Truck, CONEX	2,853.31	Infinity
L87	6	50 ft Flatcar	M35A2 Truck, M101A1 Howitzer, CONEX	1,838.09	Infinity
L96	1	50 ft Flatcar	M35A2 Truck, M105A2 Trailer, CONEX	1,854.29	Infinity

the solution. Thirteen additional troops and seven additional CONEXs could be deployed. The additional personnel capacity does not affect the movement cost. As discussed in the rail solution for the Charleston scenario, the deletion of the containers from the load plans would further decrease the total cost.

As mentioned before, several of the rail load plans are interchangeable and thereby allow other optimal combinations. The load plans meeting this criterion in the solution and their substitues follow.

Solution	Substitute
L66	L94
L67	L95
L70	L97
L74	L99
L87	L60
L96	L62

Air

Aircraft are the only transporting vehicles that can reach San Francisco within the three day deployment time considered. Discounting loading and unloading times, the aircraft require the following number of hours for this movement: C130 - 13.98, C141 - 10.62, C5 - 12.53. This is an excellent example of how the deployment time allowed can affect the transportation mode selection process. The solution generated includes the use of eleven C130 and two C141 aircraft. The load plans selected are listed in Table 16 with their cost ranges. The marginal costs are listed in Table 14. The objective function value is $154,092.54. Obviously, air movement is more expensive than motor or rail but necessary when time is the critical factor. An interesting point is that no C5 aircraft were selected. The aircraft's structural problems requiring its allowable cargo load (ACL) reduction from 265,000 pounds to 100,000 pounds under non-emergency conditions has apparently limited its cost effectiveness. The 265,000 pound ACL can be used in a wartime emergency situation.

Motor

Were the battery limited to motor transport, the load plans are obvious. Besides the unit vehicles, a tractor/semitrailer would be required to move the CONEXs. Seldom would such a situation be advantageous due to the command and control problems involved in a lengthy motor convoy. The cost for such a deployment is listed below.

M561 Truck	$ 1,035.89
M561 Truck with M101A1 Trailer	1,057.69
Two M35A2 Trucks with M332 Trailers	3,708.58
M35A2 Truck with M149 Trailer	1,854.29
M35A2 Truck with M105A2 Trailer	1,854.29
Six M35A2 Trucks with M101A1 Howitzers	11,028.54
M35A2 Truck	1,817.42
M151A2 Truck	668.76
Three M52A1 5 Ton Tractors with M127A1 12 Ton Semitrailers	3,562.29
Total Cost	$26,587.75

Rail

The model solutions for the time scenarios of seven days and thirty days illustrate the existence of two optimal solutions. Both have a minimized cost of $100,295.23. The two optimal answers are the result of identical load plans with identical costs for the two flatcar types. L62 is composed of equipment types E_2 and E_7 on a fifty-four flatcar and L70 consists of two E_2's and one E_4. The costs associated with each are $3,748.28 and $3,799.91 respectively. L96 is a fifty foot flatcar load plan equivalent to L62. L97 corresponds in a like manner

to L70. Other substitutes exist that are not pointed out by these two optimal solutions.

Solution	Substitute
L66	L94
L74	L99
L87	L60
L95	L67

The marginal costs associated with the two solutions are listed in Table 14. Optimal solutions are presented in Table 17 and 18. Cargo space is available for seven additional CONEXs.

Table 16

Optimal Solution - San Francisco - Air

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L1	5	C130	M35A2 Truck, M101A1 Howitzer, 16 Troops	$ 1,838.08	$17,863.83
L2	1	C130	M35A2 Truck, M149 Trailer, 13 Troops	1,854.29	Infinity
L3	2	C130	M35A2 Truck, M332 Trailer, 5 Troops	1,854.29	Infinity
L4	1	C130	M35A2 Truck, M105A2 Trailer, 14 Troops	8,996.38	17,082.30
L7	1	C130	M561 Truck, M101A1 Trailer, CONEX, 12 Troops	5,221.50	Infinity
L9	1	C130	M35A2 Truck, M151A2 Truck, 22 Troops	8,996.38	27,227.33
L14	1	C141	M35A2 Truck, M101A1 Howitzer, M561 Truck, 6 Troops	11,607.99	Infinity
L34	1	C141	5 CONEXs	0	20,819.05

Table 17

Optimal Solution (7 Days) - San Francisco - Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L60	6	54 ft Flatcar	M35A2 Truck, M101A1 Howitzer, CONEX	$ 0	$3,701.36
L65	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, M151A2 Truck, CONEX	4,012.25	7,746.46
L66	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, CONEX	546.70	4,280.91
L74	1	54 ft Flatcar	M561 Truck, M35A2 Truck, CONEX	3,465.55	Infinity
L95	1	50 ft Flatcar	M35A2 Truck, M149 Trailer, CONEX	0	Infinity
L96	1	50 ft Flatcar	M35A2 Truck, M105A2 Trailer, CONEX	0	Infinity
L97	1	50 ft Flatcar	M561 Truck, M101A1 Trailer, 2 CONEXs	0	Infinity
L111	1	Guard Car	6 Troops	3,562.29	Infinity
L114	9	Guard Car	9 Troops	0	6,865.09

Table 18

Optimal Solution (30 Days) - San Francisco - Rail

Load Plan	Number Required	Carrier	Equipment in Load Plan	Lower Cost	Upper Cost
L60	6	54 ft Flatcar	M35A2 Truck, M101A1 Howitzer, CONEX	$ 0	$3,701.36
L62	1	54 ft Flatcar	M35A2 Truck, M105A2 Trailer, CONEX	0	Infinity
L65	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, M151A2 Truck, CONEX	4,012.25	Infinity
L66	1	54 ft Flatcar	M35A2 Truck, M332 Trailer, CONEX	328.71	4,280.91
L70	1	54 ft Flatcar	M561 Truck, M101A1 Trailer, 2 CONEXs	0	Infinity
L74	1	54 ft Flatcar	M561 Truck, M35A2 Truck, CONEX	0	Infinity
L95	1	50 ft Flatcar	M35A2 Truck, M149 Trailer, CONEX	0	Infinity
L111	1	Guard Car	6 Troops	3,562.29	Infinity
L114	9	Guard Car	9 Troops	0	6,865.09

V. CONCLUSIONS

The model is capable of providing planning assistance for transportation operations. The linear programming techniques compiled a transportation plan consisting of the load plans associated with various carriers. The model generates solutions for operations restricted to a combination of modes or a single mode.

The research indicates that to obtain a least cost transportation asset mix, motor transportation is the principle mode to use when sufficient time allows. However, other factors must be considered. The distance to be traveled may preclude the use of motor transport due to command and control problems or time. The loss of vehicle life due to the strains of long distance moves made by tactical vehicles which are primarily designed for off road rather than highway movement must be considered as well as the fatigue of the unit personnel after a lengthy motor convoy. These factors may be important enough to replace the desire for minimized cost.

The model could be easily adapted for other route scenarios and for additional types of carriers. The parameters specified in the general model allow for expansion of the model. The addition of other carrier types would require the determination of the load plans applicable to the new carriers. Increasing the number of load plans would increase the computational effort required by the computer but pose no problems with the model design. Model parameters denoting each carrier

considered change. Other routes can be studied by using the characteristics applicable for each route (mileages, speeds, loading ramps, etc.) instead of those used here.

One limitation to the model is the difficulty of rapid fuel cost changes. Cost figures used were obtained during an eight week period so that they would accurately reflect the proper relationship between the rates for the various modes. Due to the recent oil price increase, the cost figures are already obsolete. However, assuming the fuel costs for all modes rise relatively, the load plan mix derived should remain the same. For the model to be used in day to day planning, cost data will require constant updating.

Some inaccuracy is introduced in the formula for determining the time available for loading. The model assumes an average loading/unloading time based on the number of ramps or spaces available.

One severe problem with this model is the requirement to manually generate load plans for the various carriers. For this thesis, 114 load plans were compiled in that manner. One can readily see the difficulty of doing this for a transportation mission involving a unit larger than a battery or more transporting vehicles than allowed here. As pointed out in the discussion of the rail solutions, these 114 load plans are somewhat lacking. Therefore, to fully utilize this model, some means to generate all feasible load plans is required. A computer simulation model to provide this input would greatly ease the work required before using the model.

Any military unit with computer facilities could use this model to assist it in planning movements. One great difficulty that units

have is changing the movement plan when one of its vehicles is lost due to a maintenance problem. Similar difficulties result from losing a transporting vehicle. To alleviate that problem, a computer system with remote terminals at various strategic locations and the unit's table of organization stored on some type of direct access device could be installed. Then the movement control personnel could input the additions or deletions to the equipment list and the computer could provide a printed copy of the load plans to be used. Of course, a system such as that is beyond the scope of this thesis and would cost a great deal to develop. However, the transportation planning process would certainly be facilitated by such a system. This would provide the unit personnel with more time to accomplish their primary missions. Time is always important.

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APPENDIX A

LOAD PLAN COMPOSITION, WEIGHT, AND COST

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost[a]	Cost Including Expected Damages
1	16							1			24,890	2,478.00 (10,551.00)	2,482.96 (10,572.10)
2	13					1					24,777	2,478.00 (10,551.00)	2,482.96 (10,572.10)
3	5				1						24,900	2,478.00 (10,551.00)	2,482.96 (10,572.10)
4	14						1				24,810	2,478.00 (10,551.00)	2,482.96 (10,572.10)
5	22			1							16,670	2,478.00 (10,551.00)	2,482.96 (10,572.10)
6	22			1						1	18.960	2,478.00 (10,551.00)	2,482.96 (10,572.10)
7	12	1		1							24,770	2,478.00 (10,551.00)	2,482.96 (10,572.10)
8	22								1		21,450	2,478.00 (10,551.00)	2,482.96 (10,572.10)
9	22								1	1	23,740	2,478.00 (10,551.00)	2,482.96 (10,572.10)
10	7	2								1	24,970	2,478.00 (10,551.00)	2,482.96 (10,572.10)

[a]The first number listed is for the Charleston deployment. Figures in parentheses correspond to San Francisco movement. A (-) indicates that the load plan is not used for the San Francisco movement. Load composition is the same for both routes.

AD-A076 156 ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA F/G 15/5
A LINEAR PROGRAMMING MODEL TO DETERMINE THE LEAST-COST TRANSPOR--ETC(U
DEC 79 J M HOUSE

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Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
11	16	2									19,840	2,478.00 (10,551.00)	2,482.96 (10,572.10)
12	64										15,360	2,478.00 (10,551.00)	2,482.96 (10,572.10)
13	4							1	1		38,180	3,872.00 (18,862.00)	3,879.74 (18,899.72)
14	6		1					1			31,030	3,872.00 (18,862.00)	3,879.74 (18,899.72)
15	8							1		1	25,260	3,872.00 (18,862.00)	3,879.74 (18,899.72)
16	6	2						1			43,490	3,872.00 (18,862.00)	3,879.74 (18,899.72)
17	4					1			1		38,787	3,872.00 (18,862.00)	3,879.74 (18,899.72)
18	6		1			1					31,637	3,872.00 (18,862.00)	3,879.74 (18,899.72)
19	8					1				1	25,867	3,872.00 (18,862.00)	3,879.74 (18,899.72)
20	8	2				1					44,577	3,872.00 (18,862.00)	3,879.74 (18,899.72)
21	4				1				1		40,830	3,872.00 (18,862.00)	3,879.74 (18,899.72)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
22	6		1		1						33,680	3,872.00 (18,862.00)	3,879.74 (18,899.72)
23	8				1					1	27,910	3,872.00 (18,862.00)	3,879.74 (18,899.72)
24	8	2			1						46,620	3,872.00 (18,862.00)	3,879.74 (18,899.72)
25	4						1		1		38,580	3,872.00 (18,862.00)	3,879.74 (18,899.72)
26	6		1				1				31,430	3,872.00 (18,862.00)	3,879.74 (18,899.72)
27	8						1			1	25,660	3,872.00 (18,862.00)	3,879.74 (18,899.72)
28	8	2					1				44,370	3,872.00 (18,862.00)	3,879.74 (18,899.72)
29	4			1					1		29,480	3,872.00 (18,862.00)	3,879.74 (18,899.72)
30	6			1	1					1	39,060	3,872.00 (18,862.00)	3,879.74 (18,899.72)
31	10			1	1						22,330	3,872.00 (18,862.00)	3,879.74 (18,899.72)
32	14	2		1							35,750	3,872.00 (18,862.00)	3,879.74 (18,899.72)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
33	6		1						1		28,440	3,872.00 (18,862.00)	3,879.74 (18,899.72)
34		5									52,500	3,872.00 (18,862.00)	3,879.74 (18,899.72)
35	14	4								1	47,650	3,872.00 (18,862.00)	3,879.74 (18,899.72)
36	100										24,000	3,872.00 (18,862.00)	3,879.74 (18,899.72)
37	18			1				4			99,910	43,747.00 (57,972.00)	43,834.49 (58,087.94)
38	30		1					4			99,940	43,747.00 (57,972.00)	43,834.49 (58,087.94)
39	20		1					4		1	99,830	43,747.00 (57,972.00)	43,834.49 (58,087.94)
40	22	1						4			99,980	43,747.00 (57,972.00)	43,834.49 (58,087.94)
41	14			1		1	1	2			99,957	43,747.00 (57,972.00)	43,834.49 (58,087.94)
42	26		1			1	1	2			99,987	43,747.00 (57,972.00)	43,834.49 (58,087.94)
43	16		1			1	1	2		1	99,877	43,747.00 (57,972.00)	43,834.49 (58,087.94)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
44	17	1				1	1	2			99,787	43,747.00 (57,972.00)	43,834.49 (58,087.94)
45	30				2			2		1	99,950	43,747.00 (57,972.00)	43,834.49 (58,087.94)
46	39				2	1	1				99,867	43,747.00 (57,972.00)	43,834.49 (58,087.94)
47	30				2	1	1			1	99,997	43,747.00 (57,972.00)	43,834.49 (58,087.94)
48	15	1	1	1	2				1	1	99,890	43,747.00 (57,972.00)	43,834.49 (58,087.94)
49	39	6		1					1		99,920	43,747.00 (57,972.00)	43,834.49 (58,087.94)
50	37	5	1	1					1	1	99,770	43,747.00 (57,972.00)	43,834.49 (58,087.94)
51	6		1								9,980	94.88 (1,028.69)	95.54 (1,035.89)
52	6			1							12,830	97.91 (1,050.34	98.60 (1,057.69)
53	2				1						24,950	128.46 (1,841.40)	129.36 (1,854.29)
54	10					1					24,057	128.46 (1,841.40)	129.36 (1,854.29)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
55	10						1				23,850	128.46 (1,841.40)	129.36 (1,854.29)
56	10							1			23,450	125.01 (1,825.31)	125.89 (1,838.09)
57	6								1		18,570	123.34 (1,804.79)	124.20 (1,817.42)
58	4									1	3,250	56.59 (664.11)	56.99 (668.76)
59		2									21,000	253.55 (1,179.18)	255.32 (1,187.43)
60		1						1			31,550	402.25 (3,697.66)	402.65 (3,701.36)
61		6									63,000	748.20 (5,833.80)	748.95 (5,839.63)
62		1					1				31,950	406.65 (3,744.54)	407.06 (3,748.28)
63		1					1			1	34,240	431.84 (4,012.93)	432.27 (4,016.94)
64					1					1	25,990	341.09 (-)	341.43 (-)
65		1			1					1	36,490	456.59 (4,276.63)	457.05 (4,280.91)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
66		1			1						34,200	431.40 (4,008.24)	431.83 (4,012.25)
67		1				1					32,157	408.93 (3,768.80)	409.34 (3,772.57)
68		1				1				1	34,947	439.62 (4,095.79)	440.06 (4,099.89)
69		1		1						1	24,180	321.18 (-)	321.50 (-)
70		2		1							32,390	411.49 (3,796.11)	411.90 (3,799.91)
71		3		1							42,890	526.99 (4,233.24)	527.52 (4,237.47)
72			1						1		24,710	327.01 (-)	327.34 (-)
73			1						1	1	27,000	352.20 (-)	352.55 (-)
74		1	1						1		35,210	442.51 (4,126.61)	442.95 (4,130.74)
75		4							1		58,170	695.07 (5,741.38)	695.77 (5,747.12)
76		2							1	1	39,460	489.26 (4,624.71)	489.75 (4,629.33)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
77		3	1							1	42,330	520.83 (4,177.97)	521.35 (4,182.15)
78		2	1							1	31,830	405.33 (3,730.48)	405.74 (3,734.21)
79		5	1								61,040	726.64 (5,652.30)	727.37 (5,657.95)
80		4	1								50,540	611.14 (4,988.30)	611.75 (4,993.29)
81		3	1								40,040	495.64 (3,951.95)	496.14 (3,955.90)
82		2	1								29,540	380.14 (-)	380.52 (-)
83		6								1	65,290	773.39 (6,045.85)	774.16 (6,051.90)
84		5								1	54,790	657.89 (5,407.77)	658.55 (5,413.18)
85		4								1	44,290	542.39 (5,190.79)	542.93 (5,195.98)
86		3								1	33,790	426.89 (3,960.19)	427.32 (3,964.15)
87		1						1			31,550	402.25 (3,697.66)	402.65 (3,701.36)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
88		6									63,000	748.20 (5,833.80)	748.95 (5,839.63)
89		6								1	65,290	773.39 (6,045.85)	774.16 (6,051.90)
90		5								1	54,790	657.89 (5,407.77)	658.55 (5,413.18)
91		4								1	44,290	542.39 (4,371.42)	542.93 (4,375.79)
92		3								1	33,790	426.89 (3,960.19)	427.32 (3,964.15)
93					1					1	25,990	341.09 (-)	341.43 (-)
94		1			1						34,200	431.40 (4,008.24)	431.83 (4,012.25)
95		1				1					32,157	408.93 (3,768.80)	409.34 (3,772.75)
96		1					1				31,950	406.65 (3,744.54)	407.06 (3,748.28)
97		2		1							32,390	411.49 (3,796.11)	411.90 (3,799.91)
98			1						1		24,710	327.01 (-)	327.34 (-)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
99		1	1						1		35,210	442.51 (4,126.61)	442.95 (4,130.74)
100		4							1		58,170	695.07 (5,741.38)	695.77 (5,747.62)
101		2							1	1	39,460	489.26 (4,624.71)	489.75 (4,629.33)
102		3	1							1	42,330	520.83 (4,177.97)	521.35 (4,182.15)
103		2	1							1	31,830	405.33 (3,730.48)	405.74 (3,734.21)
104		4	1								50,540	611.14 (4,988.30)	611.75 (4,993.29)
105		3	1								40,040	495.64 (3,951.95)	496.14 (3,955.90)
106		2	1								29,540	380.14 (-)	380.52 (-)
107	2										480	496.39 (3,303.04)	496.89 (3,306.34)
108	3										720	537.40 (3,620.32)	537.94 (3,623.94)
109	4										960	578.41 (3,937.60)	578.99 (3,941.54)

Load Plan Number	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Weight	Cost	Cost Including Expected Damages
110	5										1,200	619.42 (4,254.88)	620.04 (4,259.13)
111	6										1,440	660.43 (4,572.16)	661.09 (4,576.73)
112	7										1,680	701.44 (4,889.44)	702.14 (4,894.33)
113	8										1,920	742.45 (5,206.72)	743.19 (5,211.93)
114	9										2,160	783.46 (5,524.00)	784.24 (5,529.52)

APPENDIX B

COST COMPONENTS

Total costs including damages can be found in Appendix A.

Air

Aircraft	Charleston Rate	San Francisco Rate	% Damages
C130	$ 2,478.00	$10,551.00	0.2
C141	3,872.00	18,862.00	0.2
C5	43,747.00	57,972.00	0.2

Rail

Car	Charleston Rate	San Francisco Rate	% Damages
54 Foot Flatcar	$ 1.33 cwt 24,000 lb minimum	$ 11.72 cwt 30,000 lb minimum	0.1
	1.10 cwt over 24,000 lb	9.87 cwt 40,000 lb minimum	0.1
		9.26 cwt 60,000 lb minimum	0.1
50 Foot Flatcar	1.33 cwt 24,000 lb minimum	11.72 cwt 30,000 lb minimum	0.1
	1.10 cwt over 24,000 lb	9.87 cwt 40,000 lb minimum	0.1
		9.26 cwt 60,000 lb minimum	0.1
Guard Car	414.37 per car	2,668.48 per car	0.1
	41.01 per person	317.28 per person	0.1

Motor

Item Costs

Diesel Fuel:	$ 0.78 per gallon	M101A1 Howitzer Tire:	$ 23.86
Gasoline:	0.86 per gallon	M101A1 Trailer Tire:	43.30
GAA Lubricant:	1.82 per 5 gallon pail	M105A2 Tire:	73.21
6030 Lubricant:	7.65 per 5 gallon can	M332 Tire:	73.21
6090 Lubricant:	8.76 per 5 gallon can	M52A1 Tire:	108.00
Brake Fluid:	4.99 per gallon	M127A1 Tire:	108.00
M35A2 Tire:	73.21	M149 Tire:	73.21
M561 Tire:	93.21	M35A2 Engine:	7,100.00
M151A2 Tire:	23.86		

Expenditures[a]	Charleston Amount	Charleston Cost	San Francisco Amount	San Francisco Cost
GAA	. . .	$ . . .	5.00 gallons	$ 1.82
6030	5.00 gallons	7.65	25.00 gallons	38.25
6090	. . .	. . .	5.00 gallons	8.76
Brake Fluid	. . .	. . .	1.00 gallon	4.99
M35A2 Tires	. . .	. . .	4	292.84
M561 Tires	. . .	. . .	2	186.42
M101A1 Howitzer Tires	. . .	. . .	2	47.72
Diesel Fuel				
M35A2: 5 miles/gallon	73.40 gallons	57.25	497.20 gallons	387.82
M561: 7 miles/gallon	52.43 gallons	40.89	355.14 gallons	277.01
M52A1: 6 miles/gallon	61.17 gallons	47.71	414.33 gallons	323.18
Gasoline				
M151A2: 9 miles/gallon	40.78 gallons	35.07	276.22 gallons	237.55
M35A2 Engine	. . .	. . .	1	7,100.00
Repair Parts for Unit	. . .	200.00	. . .	. . .
Repair Parts for Tractor/ Semitrailer	. . .	100.00	. . .	100.00
Tire Depreciation - Trucks*				
M35A2 (10 tires)	7.0% of tread	51.25	50% of tread	366.05
M561 (6 tires)	7.0% of tread	39.15	50% of tread	279.63
M151A2 (4 tires)	7.0% of tread	6.68	50% of tread	47.72
M52A1 (10 tires)	7.0% of tread	75.60	50% of tread	540.00
Tire Depreciation - Pulled Loads*				
M101A1 Howitzer (2 tires)	3.5% of tread	1.67	25% of tread	11.93
M101A1 Trailer)2 tires)	3.5% of tread	3.03	25% of tread	21.65
M105A2 (2 tires)	3.5% of tread	5.12	25% of tread	36.61
M149 (2 tires)	3.5% of tread	5.12	25% of tread	36.61
M332 (2 tires)	3.5% of tread	5.12	25% of tread	36.61
M127A1 (8 tires)	3.5% of tread	30.24	25% of tread	216.00

[a]All figures were prorated as a cost per vehicle depending on the number of vehicles of that type.

*Truck tire depreciation was estimated for the San Francisco route then prorated for the Charleston route based on the mileage differential.

**Trailer tire depreciation was determined in the same manner as truck tire depreciation.

Vehicle	Charleston Rate	San Francisco Rate	% Damages
M35A2	$123.34	$1,804.79	0.7
M35A2 with M101A1 Howitzer	125.01	1,825.31	0.7
M35A2 with Trailer (all types)	128.46	1,841.40	0.7
M561	94.88	1,028.69	0.7
M561 with Trailer	97.91	1,050.34	0.7
M151A2	56.59	664.11	0.7
M52A1 with M127A1	253.55	1,179.18	0.7

All cost figures assume no per diem allowances are due the personnel involved in the movement.

APPENDIX C

MOTOR CREW CHANGING, MAINTENANCE, AND REFUELING TIMES

Charleston

Crew Changing Time

Driving Hours: $\frac{\text{Distance}}{\text{Speed}} = \frac{367}{45} = 8.15$

10 Minute Rest Halts: $\frac{\text{Driving Hours - 1 Hour}}{\text{2 Hours}} = \frac{8.15 - 1}{2} = 3.58 \approx 4$

15 Minute Rest Halts: 1 (at end of the first hour)

Hours Between Refueling Stops:

Fuel Capacity X Mileage of Most Restrictive Vehicle = Cruising Range

$17 \times 9 = 153$ (for the M151A2 $\frac{1}{4}$Ton Truck)

$$\frac{\text{Cruising Range}}{\text{Speed}} = \text{Hours Between Refueling Stops}$$

$$\frac{153}{45} = 3.40$$

Refueling Stops Required: $\frac{\text{Driving Hours}}{\text{Hours Between Refueling Stops}} = \frac{8.15}{3.4} = 2.40$

≈ 3

Meal Stops: 1 for 30 minutes

Total Time: 15 + 30 = 45 minutes or .75 hours

The 10 minute rest stops are absorbed by the meal and refueling stops.

Maintenance Time

Approximately one day will probably be lost due to maintenance on a trip the length of the San Francisco movement (Files, 1979a). Prorating this to the mileage for the Charleston movement results in the following answer:

$$\frac{367}{2{,}486}\ (24) = 3.54 \text{ hours}$$

Refueling Time

Refueling Stops X 10 Minutes = 3 X 10 = 30 minutes or 0.5 hours

San Francisco

Crew Changing Time

Driving Hours: $\frac{\text{Distance}}{\text{Speed}} = \frac{2{,}486}{45} = 55.24$

10 Minute Rest Halts: $\frac{\text{Driving Hours - 1 Hour}}{\text{2 Hours}} = \frac{55.24 - 1}{2} = 27.12 \approx 28$

15 Minute Rest Halts: 1 (at end of the first hour)

Hours Between Refueling Stops: 3.40

Refueling Stops Required: $\frac{\text{Driving Hours}}{\text{Hours Between Refueling Stops}} = \frac{55.24}{3.4} = 16.25$

≈ 17

Meal Stops: 9 for 30 minutes

Total Time: 15 + 2(10) + 9(30) = 305 minutes or 5.08 hours

Twenty-six of the 10 minute breaks are absorbed by the meal and refueling stops.

Maintenance Time

Approximately one day or 24 hours will probably be lost to maintenance.

Refueling Time

Refueling Stops X 10 minutes = 17 X 10 = 170 minutes or 2.83 hours

APPENDIX D

INPUT PROGRAM LISTING

```
          PROGRAM
          INITIALZ
          MOVE(XPBNAME,'DEPLOY')
          MOVE(XDATA,'REDLEG')
          CONVERT
          MOVE(XRHS,'RESPRICE')
          MOVE(XOBJ,'BTRY')
          SETUP('BOUND','INBOUND1')
          OPTIMIZE
          XANENLOG=0
          OPTIMIX
          RANGE
          EXIT
          PEND
NAME              REDLEG
ROWS
 N   BTRY
 G   E1
 G   E2
 G   E3
 G   E4
 G   E5
 G   E6
 G   E7
 G   E8
 G   E9
 G   E10
 L   A1
 L   A2
 L   A3
 L   A4
 L   A5
 L   A6
 L   A7
 L   A8
 L   A9
 L   A10
 L   A11
 L   A12
 L   A13
 L   A14
 L   A15
 L   DT1
 L   DT2
 L   DT3
 L   DT4
 L   DT5
 L   DT6
 L   DT7
 L   DT8
 L   DT9
 L   DT10
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 L  DT11
 L  DT12
 L  DT13
 L  DT14
 L  DT15
 L  F
 L  TF
COLUMNS
    CANNON        'MARKER'                     'INTORG'
    L1            BTRY           10572.10      E1                  16.00
    L1            F3                 1.00      A1                   1.00
    L1            DT1                 .07
    L2            BTRY           10572.10      E1                  13.00
    L2            F6                 1.00      A1                   1.00
    L2            DT1                 .07
    L3            BTRY           10572.10      E1                   5.00
    L3            F5                 1.00      A1                   1.00
    L3            DT1                 .07
    L4            BTRY           10572.10      E1                  14.00
    L4            F7                 1.00      A1                   1.00
    L4            DT1                 .07
    L5            BTRY           10572.10      E1                  22.00
    L5            F4                 1.00      A1                   1.00
    L5            DT1                 .07
    L6            BTRY           10572.10      E1                  22.00
    L6            F8                 1.00      E10                  1.00
    L6            A1                 1.00      DT1                   .12
    L7            BTRY           10572.10      E1                  12.00
    L7            F2                 1.00      F4                   1.00
    L7            A1                 1.00      DT1                   .20
    L8            BTRY           10572.10      E1                  22.00
    L8            F9                 1.00      A1                   1.00
    L8            DT1                 .06
    L9            BTRY           10572.10      E1                  22.00
    L9            F9                 1.00      E10                  1.00
    L9            A1                 1.00      DT1                   .10
    L10           BTRY           10572.10      E1                   7.00
    L10           F2                 2.00      F10                  1.00
    L10           A1                 1.00      DT1                   .29
    L11           BTRY           10572.10      E1                  16.00
    L11           F2                 2.00      A1                   1.00
    L11           DT1                 .27
    L12           BTRY           10572.10      E1                  64.00
    L12           A1                 1.00      DT1                   .04
    L13           BTRY           18899.72      E1                   4.00
    L13           F8                 1.00      E3                   1.00
    L13           A2                 1.00      DT2                   .21
    L14           BTRY           18899.72      E1                   6.00
    L14           F3                 1.00      E8                   1.00
    L14           A2                 1.00      DT2                   .23
    L15           BTRY           18899.72      E1                   3.00
    L15           F3                 1.00      F10                  1.00
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L15	A2	1.00	DT2	.21
L16	BTRY	18899.72	E1	6.00
L16	E2	2.00	E8	1.00
L16	A2	1.00	DT2	.54
L17	BTRY	18899.72	E1	4.00
L17	E6	1.00	E9	1.00
L17	A2	1.00	DT2	.21
L18	BTRY	18899.72	E1	6.00
L18	E3	1.00	E6	1.00
L18	A2	1.00	DT2	.23
L19	BTRY	18899.72	E1	8.00
L19	E6	1.00	E10	1.00
L19	A2	1.00	DT2	.21
L20	BTRY	18899.72	E1	8.00
L20	E2	2.00	E6	1.00
L20	A2	1.00	DT2	.54
L21	BTRY	18899.72	E1	8.00
L21	E5	1.00	E9	1.00
L21	A2	1.00	DT2	.14
L22	BTRY	18899.72	E1	6.00
L22	E3	1.00	E5	1.00
L22	A2	1.00	DT2	.23
L23	BTRY	18899.72	E1	8.00
L23	E5	1.00	E10	1.00
L23	A2	1.00	DT2	.21
L24	BTRY	18899.72	E1	8.00
L24	E2	2.00	E5	1.00
L24	A2	1.00	DT2	.54
L25	BTRY	18899.72	E1	4.00
L25	E7	1.00	E9	1.00
L25	A2	1.00	DT2	.21
L26	BTRY	18899.72	E1	6.00
L26	E3	1.00	E7	1.00
L26	A2	1.00	DT2	.23
L27	BTRY	18899.72	E1	8.00
L27	E7	1.00	E10	1.00
L27	A2	1.00	DT2	.21
L28	BTRY	18899.72	E1	8.00
L28	E2	2.00	E7	1.00
L28	A2	1.00	DT2	.54
L29	BTRY	18899.72	E1	4.00
L29	E4	1.00	E9	1.00
L29	A2	1.00	DT2	.23
L30	BTRY	18899.72	E1	6.00
L30	E4	1.00	E5	1.00
L30	E10	1.00	A2	1.00
L30	DT2	.34		
L31	BTRY	18899.72	E1	10.00
L31	E4	1.00	E5	1.00
L31	A2	1.00	DT2	.26
L32	BTRY	18899.72	E1	14.00
L32	E2	2.00	E8	1.00

L32	A2	1.00	DT2	.56
L33	BTRY	18899.72	E1	6.00
L33	F3	1.00	E9	1.00
L33	A2	1.00	DT2	.19
L34	BTRY	18899.72	E2	5.00
L34	A2	1.00	DT2	1.00
L35	BTRY	18899.72	E1	14.00
L35	F2	4.00	E10	1.00
L35	A2	1.00	DT2	.33
L36	BTRY	18899.72	E1	100.00
L36	A2	1.00	DT2	.07
L37	BTRY	58087.94	E1	13.00
L37	F4	1.00	E8	4.00
L37	A3	1.00	DT3	.33
L38	BTRY	58087.94	E1	30.00
L38	F3	1.00	E8	4.00
L38	A3	1.00	DT3	.81
L39	BTRY	58087.94	E1	20.00
L39	F3	1.00	E8	4.00
L39	F10	1.00	A3	1.00
L39	DT3	.95		
L40	BTRY	58087.94	E1	22.00
L40	F2	1.00	E8	4.00
L40	A3	1.00	DT3	.98
L41	BTRY	58087.94	E1	10.00
L41	F1	1.00	E6	1.00
L41	F7	1.00	E8	2.00
L41	A3	1.00	DT3	.89
L42	BTRY	58087.94	E1	26.00
L42	F3	1.00	E6	1.00
L42	F7	1.00	E8	2.00
L42	A3	1.00	DT3	.81
L43	BTRY	58087.94	E1	16.00
L43	F3	1.00	E6	1.00
L43	F7	1.00	E8	2.00
L43	E10	1.00	A3	1.00
L43	DT3	.95		
L44	BTRY	58087.94	E1	17.00
L44	F2	1.00	E6	1.00
L44	F7	1.00	E8	2.00
L44	A3	1.00	DT3	1.01
L45	BTRY	58087.94	E1	30.00
L45	F5	2.00	E8	2.00
L45	F10	1.00	A3	1.00
L45	DT3	.81		
L46	BTRY	58087.94	E1	32.00
L46	F5	2.00	E6	1.00
L46	F7	1.00	A3	1.00
L46	DT3	.84		
L47	BTRY	58087.94	E1	30.00
L47	F5	2.00	E6	1.00
L47	F7	1.00	E10	1.00

L47	A3	1.00	DT3	.95
L48	BPRY	58087.98	F1	15.00
L48	F2	1.00	F3	1.00
L48	F4	1.00	F5	2.00
L48	F9	1.00	F10	1.00
L48	A3	1.00	DT3	1.25
L49	BPRY	58057.98	F1	33.00
L49	F2	6.00	F4	1.00
L49	F9	1.00	A3	1.00
L49	DT3	2.30		
L50	BPRY	58087.98	F1	37.00
L50	F2	5.00	F3	1.00
L50	F4	1.00	F9	1.00
L50	F10	1.00	A3	1.00
L50	DT3	2.31		
L51	BPRY	1035.38	F1	6.00
L51	F3	1.00	A4	1.00
L51	DT4	.18		
L52	BPRY	1057.69	F1	6.00
L52	F4	1.00	A5	1.00
L52	DT5	.18		
L53	BPRY	1354.29	F1	2.00
L53	F5	1.00	A6	1.00
L53	DT6	.24		
L54	BPRY	1354.29	F1	10.00
L54	F6	1.00	A7	1.00
L54	DT7	.24		
L55	BPRY	1354.29	F1	10.00
L55	F7	1.00	A8	1.00
L55	DT8	.24		
L56	BPRY	1333.02	F1	10.00
L56	F8	1.00	A9	1.00
L56	DT9	.24		
L57	BPRY	1317.42	F1	6.00
L57	F9	1.00	A10	1.00
L57	DT10	.24		
L58	BPRY	668.76	F1	4.00
L58	F10	1.00	A11	1.00
L58	DT11	.18		
L59	BPRY	1137.43	F2	2.00
L59	A12	1.00	DT12	1.00
L60	BPRY	3701.36	F2	1.00
L60	F3	1.00	A13	1.00
L60	DT13	.50	F	1.00
L60	FF	31558.00		
L61	BPRY	5839.62	F2	6.00
L61	A13	1.00	DT13	1.20
L61	F	1.00	FF	63000.00
L62	BPRY	3743.28	F2	1.00
L62	F7	1.00	A13	1.00
L62	DT13	.50	F	1.00
L62	FF	31950.00		

L63	BTRY	4016.94	E2	1.00
L63	E7	1.00	E10	1.00
L63	A13	1.00	DT13	1.20
L63	F	1.00	TE	34240.00
L65	BTRY	4280.91	E2	1.00
L65	E5	1.00	E10	1.00
L65	A13	1.00	DT13	.70
L65	F	1.00	TE	36490.00
L66	BTRY	4012.25	E2	1.00
L66	E5	1.00	A13	1.00
L66	DT13	.50	F	1.00
L66	TE	34200.00		
L67	BTRY	3772.57	E2	1.00
L67	E6	1.00	A13	1.00
L67	DT13	.50	F	1.00
L67	TE	32157.00		
L68	BTRY	4099.80	E2	1.00
L68	E6	1.00	E10	1.00
L68	A13	1.00	DT13	.70
L69	F	1.00	TE	34947.00
L70	BTRY	3799.91	E2	2.00
L70	E4	1.00	A13	1.00
L70	DT13	.80	F	1.00
L70	TE	32390.00		
L71	BTRY	4237.47	E2	3.00
L71	E4	1.00	A13	1.00
L71	DT13	1.00	F	1.00
L71	TE	42890.00		
L74	BTRY	4130.74	E2	1.00
L74	E3	1.00	E9	1.00
L74	A13	1.00	DT13	.70
L74	F	1.00	TE	35210.00
L75	BTRY	5747.12	E2	4.00
L75	E3	1.00	A13	1.00
L75	DT13	1.00	F	1.00
L75	TE	58170.00		
L76	BTRY	4629.33	E2	2.00
L76	E3	1.00	E10	1.00
L76	A13	1.00	DT13	.80
L76	F	1.00	TE	39460.00
L77	BTRY	4182.15	E2	3.00
L77	E3	1.00	E10	1.00
L77	A13	1.00	DT13	1.10
L77	F	1.00	TE	42330.00
L78	BTRY	3734.21	E2	2.00
L78	E3	1.00	E10	1.00
L78	A13	1.00	DT13	.90
L78	F	1.00	TE	31830.00
L79	BTRY	5657.95	E2	5.00
L79	E3	1.00	A13	1.00
L79	DT13	1.30	F	1.00
L79	TE	61040.00		

L80	BTRY	4993.29	E2	4.00
L80	F3	1.00	A13	1.00
L80	DT13	1.10	F	1.00
L80	TE	50540.00		
L81	BTRY	3955.90	E2	3.00
L81	F3	1.00	A13	1.00
L81	DT13	.90	F	1.00
L81	TE	40040.00		
L83	BTRY	6051.90	E2	6.00
L83	A13	1.00	DT13	1.40
L83	F	1.00	TE	65290.00
L84	BTRY	5413.18	E2	5.00
L84	A13	1.00	DT13	1.20
L84	F	1.00	TE	54790.00
L85	BTRY	5195.93	E2	4.00
L85	A13	1.00	DT13	1.00
L85	F	1.00	TE	44290.00
L86	BTRY	3964.15	E2	3.00
L86	A13	1.00	DT13	.80
L86	F	1.00	TE	33790.00
L87	BTRY	3701.36	E2	1.00
L87	F8	1.00	A14	1.00
L87	DT14	.50	F	1.00
L87	TE	31550.00		
L88	BTRY	5839.63	E2	5.00
L88	A14	1.00	DT14	1.20
L88	F	1.00	TE	63000.00
L89	BTRY	6051.90	E2	6.00
L89	F10	1.00	A14	1.00
L89	DT14	1.40	F	1.00
L89	TE	65290.00		
L90	BTRY	5413.18	E2	5.00
L90	F10	1.00	A14	1.00
L90	DT14	1.20	F	1.00
L90	TE	54790.00		
L91	BTRY	4375.79	E2	4.00
L91	F10	1.00	A14	1.00
L91	DT14	1.00	F	1.00
L91	TE	44290.00		
L92	BTRY	3964.15	E2	3.00
L92	F10	1.00	A14	1.00
L92	DT14	.80	F	1.00
L92	TE	33790.00		
L94	BTRY	4012.25	E2	1.00
L94	F5	1.00	A14	1.00
L94	DT14	.50	F	1.00
L94	TE	34200.00		
L95	BTRY	3772.57	E2	1.00
L95	F6	1.00	A14	1.00
L95	DT14	.50	F	1.00
L95	TE	32157.00		
L96	BTRY	3748.28	E2	1.00

L96	F7	1.00	A14	1.00
L96	DT14	.50	F	1.00
L96	TF	31950.00		
L97	BFRY	3799.21	F2	2.00
L97	F4	1.00	A14	1.00
L97	DT14	.80	F	1.00
L97	TF	22390.00		
L99	BFRY	4130.76	F2	1.00
L99	F3	1.00	F9	1.00
L99	A14	1.00	DT14	.70
L99	F	1.00	TF	35210.00
L100	BFRY	5787.62	F2	4.00
L100	F3	1.00	A14	1.00
L100	DT14	1.00	F	1.00
L100	TF	58170.00		
L101	BFRY	4629.33	F2	2.00
L101	F9	1.00	F10	1.00
L101	A14	1.00	DT14	.80
L101	F	1.00	TF	39460.00
L102	BFRY	4182.15	F2	3.00
L102	F3	1.00	F10	1.00
L102	A14	1.00	DT14	1.10
L102	F	1.00	TF	42330.00
L103	BFRY	3739.21	F2	2.00
L103	F3	1.00	F10	1.00
L103	A14	1.00	DT14	.90
L103	F	1.00	TF	31830.00
L104	BFRY	4993.21	F2	4.00
L104	F3	1.00	A14	1.00
L104	DT14	1.10	F	1.00
L104	TF	59540.00		
L105	BFRY	3955.90	F2	3.00
L105	F3	1.00	A14	1.00
L105	DT14	.90	F	1.00
L105	TF	40040.00		
L107	BFRY	3306.39	F1	2.00
L107	A15	1.00	DT15	.08
L107	F	1.00	TF	480.00
L108	BFRY	3623.94	F1	3.00
L108	A15	1.00	DT15	.08
L108	F	1.00	TF	720.00
L109	BFRY	3941.54	F1	4.00
L109	A15	1.00	DT15	.08
L109	F	1.00	TF	960.00
L110	BFRY	4259.13	F1	5.00
L110	A15	1.00	DT15	.08
L110	F	1.00	TF	1200.00
L111	BFRY	4576.73	F1	6.00
L111	A15	1.00	DT15	.08
L111	F	1.00	TF	1440.00
L112	BFRY	4894.33	F1	7.00
L112	A15	1.00	DT15	.08

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    L112      F                 1.00     TE              1680.00
    L113      BTRY           5211.93     E1                 3.00
    L113      A15               1.00     DT15                .08
    L113      F                 1.00     TE              1920.00
    L114      BTRY           5523.52     E1                 9.00
    L114      A15               1.00     DT15                .08
    L114      F                 1.00     TE              2160.00
    ARTY      'MARKER'                   'INTEND'
RHS
    RESTRICT  E1               87.00     E2                 6.00
    RESTRICT  E3                1.00     E4                 1.00
    RESTRICT  E5                2.00     E6                 1.00
    RESTRICT  E7                1.00     E8                 6.00
    RESTRICT  E9                1.00     E10                1.00
    RESTRICT  A1               30.00
    RESTRICT  A2               25.00
    RESTRICT  A3               15.00
    RESTRICT  A4                1.00
    RESTRICT  A5                1.00
    RESTRICT  A6                2.00
    RESTRICT  A7                1.00
    RESTRICT  A8                1.00
    RESTRICT  A9                6.00
    RESTRICT  A10               1.00
    RESTRICT  A11               1.00
    RESTRICT  A12               3.00
    RESTRICT  A13              25.00
    RESTRICT  A14              10.00
    RESTRICT  A15              10.00
    RESTRICT  DT1             154.02     DT2              157.38
    RESTRICT  DT3             155.47     DT4               68.25
    RESTRICT  DT5              68.25     DT6               68.25
    RESTRICT  DT7              68.25     DT8               68.25
    RESTRICT  DT9              68.25     DT10              68.25
    RESTRICT  DT11             68.25     DT12              55.67
    RESTRICT  DT13              9.23     DT14               9.23
    RESTRICT  DT15              9.22
    RESTRICT  F               150.00
    RESTRICT  TE          2793736.00
BOUNDS
 UP INBOUND1   L1               6.00
 UP INBOUND1   L3               2.00
 UP INBOUND1   L7               6.00
 UP INBOUND1   L10              3.00
 UP INBOUND1   L11              3.00
 UP INBOUND1   L13              6.00
 UP INBOUND1   L14              6.00
 UP INBOUND1   L15              6.00
 UP INBOUND1   L16              6.00
 UP INBOUND1   L20              3.00
 UP INBOUND1   L21              2.00
 UP INBOUND1   L22              2.00
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UP INBOUND1	L24	3.00
UP INBOUND1	L28	3.00
UP INBOUND1	L30	2.00
UP INBOUND1	L31	2.00
UP INBOUND1	L32	3.00
UP INBOUND1	L34	2.00
UP INBOUND1	L35	2.00
UP INBOUND1	L37	2.00
UP INBOUND1	L38	2.00
UP INBOUND1	L39	2.00
UP INBOUND1	L40	2.00
UP INBOUND1	L41	4.00
UP INBOUND1	L42	4.00
UP INBOUND1	L43	4.00
UP INBOUND1	L44	4.00
UP INBOUND1	L45	4.00
UP INBOUND1	L48	6.00
UP INBOUND1	L50	2.00
UP INBOUND1	L53	2.00
UP INBOUND1	L56	6.00
UP INBOUND1	L59	3.00
UP INBOUND1	L60	6.00
UP INBOUND1	L62	6.00
UP INBOUND1	L63	6.00
UP INBOUND1	L65	6.00
UP INBOUND1	L66	6.00
UP INBOUND1	L67	6.00
UP INBOUND1	L68	6.00
UP INBOUND1	L70	3.00
UP INBOUND1	L71	2.00
UP INBOUND1	L74	6.00
UP INBOUND1	L75	2.00
UP INBOUND1	L76	3.00
UP INBOUND1	L77	2.00
UP INBOUND1	L78	3.00
UP INBOUND1	L79	2.00
UP INBOUND1	L80	2.00
UP INBOUND1	L81	2.00
UP INBOUND1	L84	2.00
UP INBOUND1	L85	2.00
UP INBOUND1	L86	2.00
UP INBOUND1	L87	6.00
UP INBOUND1	L90	2.00
UP INBOUND1	L91	2.00
UP INBOUND1	L94	6.00
UP INBOUND1	L95	6.00
UP INBOUND1	L96	6.00
UP INBOUND1	L97	3.00
UP INBOUND1	L99	6.00
UP INBOUND1	L100	2.00
UP INBOUND1	L101	3.00
UP INBOUND1	L102	2.00

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UP INBOUND1   L103        3.00
UP INBOUND1   L104        2.00
UP INBOUND1   L105        2.00
UP INBOUND1   L107       10.00
UP INBOUND1   L108       10.00
UP INBOUND1   L109       10.00
UP INBOUND1   L110       10.00
UP INBOUND1   L111       10.00
UP INBOUND1   L112       10.00
UP INBOUND1   L113       10.00
UP INBOUND1   L114       10.00
ENDATA
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